NOTICE OF CHANGE

INCH–POUND

MIL–STD–1797A
NOTICE 1
28 June 1995

DEPARTMENT OF DEFENSE INTERFACE STANDARD

FLYING QUALITIES OF PILOTED AIRCRAFT

TO ALL HOLDERS OF MIL–STD–1797A:

1. MAKE THE FOLLOWING PEN AND INK CHANGES:

Cover

Delete "Military Standard" and insert "Department of Defense Interface Standard." Delete entire Distribution Statement D and substitute: "Distribution Statement A. Approved for public release; distribution is unlimited."

Page ii

Delete entire Export Control Warning and Destruction Notice.

Page 9

3.4.6, bottom of page. Delete "$\Delta\beta$" and substitute "$\Delta\beta_{max}$".

Page 38

4.6.5.3, line 3, change to read: "system due to pilot action shall not exceed . . . ".

Page 39

4.6.6.2, first sentence, change to read: "Yaw control power shall be sufficient . . .".

PAGE 58

20.3, sixth reference on page. Delete "MIL–F–25140" and substitute "MIL–W–25140".

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AMSC N/A FSC 15GP

Page 80

3.2, Requirement Guidance, Category B, line 3. Delete “light–path” and substitute “flight–path”.

Page 96

4.1.4.1, Requirement Guidance, d. Delete “Vo $_{on}$ ” and substitute “$V_{o_{min}}$(PA)”.

4.1.4.1, Requirement Guidance, d, lines 2, 3, 4, and 6. Delete “V_s” and substitute “V_S”.

Page 101

4.1.4.2, Requirement Guidance, 2.e, first line. Delete “what” and substitute “that”.

Page 103

4.1.4.3, Requirement Guidance, next to last paragraph, line 3. Change to read: “. . .sea level while remaining . . . ”.

4.1.4.3, Requirement Guidance, next to last paragraph, line 7. Change to read: “. . . (commonly used for structural . . .”.

Page 122

Figure 8, Change title to read: “Definition of Levels which include atmospheric disturbances as well as failures – Suggested by Carlson (AFFDL–TR–78–171).”

Page 137

5.1.11.2, Verification Guidance, last sentence. Change to read: “. . . will likely be at the boundaries of . . .”.

Page 139

4.1.11.4, Requirement Guidance, line 2. Change to read: “Recommended minimum time delay: A default value would be 1 second.”

4.1.11.4, Requirement Guidance, last sentence. Change to read: “Table IX and the paragraph following it are excerpts.”

Page 144

4.1.11.5, Requirement Guidance, third paragraph, line 2. Delete “$C_{1\beta}$” and substitute “$C_{\ell\beta}$”.

Page 146

5.1.11.5, Verification Guidance, third paragraph, lines 2 and 3. Change to read: “. . .To these margins must be added another nose–down control . . .”.

5.1.11.5, Verification Guidance, last paragraph, line 2. Change to read: “needed: Δ_{marg} is the sum of turbulence and sensor–noise components, Δ_{tran} provides . . .”.

Page 159

4.1.12.11, line 3. Change to read: “. . . aircraft motion produced, be conveniently and . . .”.

Page 160

4.1.12.4 through 4.1.12.11, Requirement Rationale, first line. Change to read: ". . . directly to the flight control system applies . . .".

Page 167

4.2.1.1, Requirement Guidance, Equation, last term in numerator. Change to read "e e^{s}".

Page 169

4.2 through 4.2.1.1, Requirement Lessons Learned, third paragraph, line 1. Change to read ". . . angle of attack above that for zero $1/T_{h_1}$ or d /dV. These . . .".

Page 175

4.2.1.2, Requirement Guidance, second and third expressions. Change to read:

$$\frac{M \; Z \; (1/T_{1})}{M \; [\;_{p};\;_{p}]} \quad \text{and} \quad \frac{M \; (1/T_{2}) \; e^{s}}{s \; [\;_{sp};\;_{sp}]}$$

Phugoid — Short Period

Page 177

4.2.1.2, Requirement Guidance, line 8. Change to read ". . . can be ignored, leaving the $a_z/\;_{es}$ numerator . . .".

4.2.1.2, Requirement Guidance, last paragraph, line 4. Change to read ". . . (LOES) of the $/F_{es}$ transfer function . . . .".

Page 184

4.2.1.2, Requirement Guidance, last line. Change to read ". . . short–period approximation),".

Page 187

4.2.1.2, Requirement Guidance, line 2. Change to read ". . . and 16 ft $\bar{c}$, the specified Level 1 . . .".

Page 194

Figure 25, approximately center of figure. Delete "15,2" and substitute "1.5,2".

Figure 25, legend box, P.R. Scale, second listing. Delete "COPPER–HARPER" and substitute "COOPER–HARPER".

Figure 25, title. Change to read: "Comparison of pilot ratings with Category A short–period frequency requirements."

Page 195

Figure 26, legend box, P.R. Scale, second listing. Delete "COPPER–HARPER" and substitute "COOPER–HARPER".

Page 196

Figure 27, legend box, P.R. Scale, second listing. Delete “COPPER–HARPER” and substitute “COOPER–HARPER”.

Page 197

Figure 29, legend box, P.R. Scale, second listing. Delete “COPPER–HARPER” and substitute “COOPER–HARPER”.

Figure 29, right edge of figure. Delete “Boundaries from AGARD–CP–333” and substitute “Boundaries from AGARD–CP–333, Gibson”.

Page 200

Figures 33 and 35, fourth diagonal line. Delete “LEVELS 2” and substitute “LEVEL 2”.

Figure 35, legend in upper left hand corner, last line. Delete “4,000 43” and substitute “4,000 431”.

Page 201

Figure 36. Rotate the figure 90 degrees counterclockwise.

Page 219

Next to last equation. Delete and substitute:

$$\frac{{}^{2}_{sp}}{n/} \qquad \frac{o}{n_{z_{ss}}} \cong \frac{q_{ss}\ \Delta t}{q_{ss} V_T/g} \qquad \frac{g}{V_T \Delta t}$$

Page 259

Frequency–response magnitude and phase, second equation under Exact: Delete and substitute:

$$= \pm \tan^{-1} (\quad)$$

Page 260

Equation at bottom of page. Delete and substitute:

$$\sqrt{K_q T_q M}\ \ /2$$

Page 290

4.2.7.2.1, last sentence. Change to read: “. . . result in departure or exceedance of load factor limits.”

Page 294

4.2.7.3, Lessons Learned, lines 2 and 3. Change to read: “. . . It was possible to mis–set trim for takeoff so that –24 deg deflection . . . .”.

Page 303

Table XVII, last line of section a. Change to read: "* For n_L <3, (F_s/n) is 28.0 . . . ".

Page 305

Figure 101, center of figure, denominator, twice. Delete "(n/d)" and substitute "(n/)".

Page 329

Table XVIII, last column heading. Delete "d_{as}/F_{as}" and substitute "$_{as}/F_{as}$".

Page 364

Figure 130, legend in lower right corner. Delete "REFERENCE AFFDL–TR–65–227" and "REFERENCE NASA–TND–2251" and substitute "AFFDL–TR–65–227" and "NASA–TND–2251".

Page 366

5.3.1.2, Verification Guidance, second line of equation. Delete "$-\sin(a + i_t)$" and substitute "$-\sin(+ i_t)$".

Page 375

4.4.1.1, Requirement Guidance, fifth paragraph, line 6. Change expression to read: "$(M^2\cos^2 - 1)^{-1/2}$".

Page 377

4.5.1.1, Requirement Guidance, first equation following second paragraph. Change denominator in second part of equation to read: "$(1/T_S)(1/T_R)[\ _d,\ \ _d]$".

4.5.1.1, Requirement Guidance, second equation following second paragraph. Change numerator in second part of equation to read: "$(A_3s^3 + A_2s^2 + A_1s + A_0)e^{-}\ e\,\beta$".

Page 391

First equation, last term, right hand side. Change to read: "$-2\,k_z^2\ C_{L_1}$".

Page 398

Figure 150, title. Change to read: "Composite pilot ratings for spiral descent of simulated reentry vehicle (from NASA–CR–778)."

Page 402

5.5.1.3, Verification Guidance, two large equations in middle of page. Change the denominator inside the large parentheses of both equations to read:

$$c\ \frac{g\ \ bk_z^2}{4(W/S)k_x^2}\left(C_{y_\beta}\ \ \frac{C'_{n_r}}{2k_z^2}\right)\frac{C'_{\ell_p}}{C'_{n_\beta}}$$

Page 404

4.5.1.4, Requirement Guidance, third paragraph, second line. Delete "figure 154" and substitute "figure 156".

Page 418

Second equation, last term inside the square brackets on the right side.

Delete $\frac{C'_{y_a}}{C'_{\ell_a}} C'_{\ell_\beta}$ and substitute $\frac{C_{y_a}}{C'_{\ell_a}} C'_{\ell_\beta}$

Page 429

5.5.5, Verification Guidance, last equation, denominator. Change to read:

$$C_{\ell_a}\left(1 - \frac{C_{n_a} C_{\ell_r}}{C_{\ell_a} C_{n_r}}\right)$$

Page 460

5.5.8.1, Verification Guidance, last two equations, bottom of page. Change to read:

$$k_x^2 = I_x/(mb^2)\ , \qquad k_z^2 = I_z/(mb^2)\ ,$$

Page 464

Lower right hand corner, top of second sketch. Delete “X” and substitute “x”.

Page 466

4.5.8.4, Requirement Lessons Learned, line 2. Delete “YF–15” and substitute “YC–15”.

4.5.8.4, Requirement Lessons Learned. Combine the two paragraphs into one paragraph.

Page 476

4.5.9.2, Requirement Guidance, fifth line following table. Change to read “Level 2: One–eighth of the Level 2 values in table XXXVI.”

Page 491

4.5.9.3, Requirement Guidance, fifth line from bottom of the page. Delete “(AGARD–C–333)” and substitute “(AGARD–CP–333)”.

Page 498

Matrix equation, middle of page. Change to read:

$$\begin{bmatrix} C_{\ell_\beta} \quad \frac{bg}{2V_T^2} C_{y_\beta}\left[\frac{C_{\ell_r}}{C_{L_1}} - 4\left(k_z^2 \quad k_y^2 \quad \frac{\bar{c}^2}{b^2}\right)\sin \quad \tan\right] & C_{\ell}\;{}_{a} \\ C_{n_\beta}\,\alpha \quad \frac{bg}{2V_T^2} C_{y_\beta}\left[\frac{C_{n_r}}{C_{L_1}} \quad - 4k_{xz}^2 \quad \sin \quad \tan\right] & C \;{}_{a} \end{bmatrix} \begin{bmatrix} \beta \\ \\ a \end{bmatrix}$$

$$\frac{bg}{V_T^2}\begin{bmatrix} -\frac{1}{2}C_{\ell_r}\sin \quad + C_{L_1}\left(k_z^2 \; - k_y^2 \; \frac{\bar{c}^2}{b^2}\right)\sin^2 \; \tan \\ -\frac{1}{2}C_{n_r}\sin \quad + C_{L_1} \quad k_{xz}^2 \quad \sin^2 \quad \tan \end{bmatrix}$$

Sentence following the matrix equation. Change to read:

where $C_{L_1} = W/(q\,S)$, $k_y^2 = I_y/(m\bar{c}^2)$, $k_z^2 = I_z/(mb^2)$, $k_{xz}^2 = I_{xz}/(mb^2)$; $n_y = C_{y_\beta}\,\beta/C_{L_1}$.

Page 504

4.5.9.5.7, Requirement Guidance, third paragraph, line 2. Delete “over look” and substitute “overlook”.

Page 505

4.6.1.1, Requirement Guidance, second and third equations, first term in denominator. Change to read: “$(s + 1/T_S)$

4.6.1.1, Requirement Guidance, first line following third equation. Change to read “. . .deflection controls (pilot controller deflection commands . . .”.

Page 526

5.6.1.1, Verification Guidance, fourth equation. Change to read:

$$2 \quad d \quad d \qquad \frac{Vg}{2(W/S)}\left[C_{y_\beta} \quad \frac{1}{2k_z^2} \; C'_{n_r} \quad \frac{k_z^2}{k_x^2}\;\frac{C'_{\ell_\beta}}{C'_{n_\beta}}\left(C_{L_1} \quad \frac{1}{2k_z^2}\; C'_{n_p}\right)\right]$$

5.6.1.1, Verification Guidance, first and second sentences following last equation. Change to read “$|\beta \quad|_d$ is the ratio of amplitudes of the roll and sideslip envelopes in the dutch roll mode and $C_{L_1} = W/(\bar{q}S)$. The dutch–roll envelope of roll rate, p, is shown in figure 228, from AFFDL–TR–69–72, for a step command.”

Page 529

Last equation, numerator of last term. Change to read: $C_{y\;a}\left(C_{\ell_\beta} \quad C_{n_\beta} C_{\ell\;r}/C_{n\;r}\right)$.

Page 545

4.6.2, Requirement Guidance, footnote 11, second sentence. Change to read: "The β and $\Delta\beta/k$ of figure 238 . . .".

Page 546

Paragraph 3, line 3. Change to read: ". . . For $|\beta \;|_d$ above some nominal value (5.0), . . .".

Page 552

Second line following figure. Change to read: "measurement of $_1$. The above–noted trend . . .".

Page 572

5.6.4, Verification Guidance, first equation. Change to read: $a \quad rp \qquad C'_{\ell_r} \; C'_{\ell_a} \; .$

Page 578

5.6.5.1, Verification Guidance, last three equations. Change to read:

$$C_{y_{\beta}} = C_{y_{\beta}} - C_{y_{r}} C_{hr_{\beta}}/C_{hr_{r}}$$

$$C_{n_{\beta}} = C_{n_{\beta}} - C_{n_{r}} C_{hr_{\beta}}/C_{hr_{r}}$$

$$C_{\ell_{\beta}} = C_{\ell_{\beta}} - C_{\ell_{r}} C_{hr_{\beta}}/C_{hr_{r}}$$

Page 581

5.6.6, Verification Guidance, equation. Change to read:

$$\bar{q}Sb\, C_n(\;r,\;\;a,\;\;T, \beta\;\;\dot{\beta}, P, R,\;\;, M \ldots) = I_z \dot{\;} - I_{xz}(\dot{\;} + QR) + (I_y - I_x)PQ$$

Page 584

4.6.6.2, first sentence. Change to read: "Yaw control power shall be sufficient to meet . . .".

Page 589

First equation, delete and substitute.

$$\begin{bmatrix} C_{y_{\beta}} & 0 & C_{y_{r}} \\ C_{\ell_{\beta}} & C_{\ell} & C_{\ell_{r}} \\ C_{n_{\beta}} & C_{n} & C_{n_{r}} \end{bmatrix} \begin{bmatrix} \beta \\ a \\ r \end{bmatrix} \quad \frac{g}{V} \quad \frac{b}{2V} \quad \sin \quad \begin{bmatrix} C_{y_p} \sin /\cos \qquad C_{y_r}\cos \\ \ell_p \sin /\cos \; -C_{\ell_r} \cos + 2C \cos \sin \tan \; (k_z^2 - k_y^2 c^2/b^2)\cos + k_{xz}^2 \sin /\cos \;] \\ C_{n_p} n \;\; o \;\; \alpha o \; n_r \qquad L_1 \cos \sin \tan \; (k_x^2 - k^2c^2/b^2 \sin /\cos \;\; k_{xz}^2 \cos \end{bmatrix}$$

Second equation, delete and substitute.

$C_{L1} = W/(qS),\ k_x^2 = I_x/(mb^2),\ k_y^2 = I_y/(m\bar{c}^2),\ k_z^2 = I_z/(mb^2),\ k_{xz}^2 = I_{xz}/(mb^2)$

First paragraph, line 4. Change to read "hand column $(0\ C_2\ C_3)^T$ (neglecting C_{y_p} and C_{y_r}),".

Fourth equation, delete and substitute.

$$a \quad \frac{gb \sin}{2V^2\Delta} \quad [C_2 (C_{y_\beta} C_{n_r} \quad C_{n_\beta} C_{y_r} \quad C_3 (C_{y_\beta} C_{\ell_r} \quad C_{\ell_\beta} C_{y_r}$$

Page 603

Equation inside sketch. Delete "z = x tan " and substitute "–z = x tan ".

4.8.1, Requirement Lessons Learned. Switch the order of paragraphs 1 and 2.

Page 604

5.8.1, Verification Guidance, last sentence. Change to read: ". . . the critical roll rate squared, p_{cr}^2, is".

Page 642

5.8.4.3.1, Verification Guidance, four equations, one–third of the page down from the top. Change to read:

$$L_i' \quad \frac{L_i \quad \frac{I_{xz}}{I_x} N_i}{1 - \frac{I_{xz}^2}{I_x I_z}} \quad N_i' = \frac{N_i + \frac{I_{xz}}{I_z} L_i}{1 - \frac{I_{xz}^2}{I_x I_z}}, \quad C_{\ell_i}' \quad \frac{C_{\ell_i} \quad \frac{I_{xz}}{I_z} C_{n_i}}{1 - \frac{I_{xz}^2}{I_x I_z}}, \quad C_{n_i}' \quad \frac{C_{n_i} + \frac{I_{xz}}{I_x} C_{\ell_i}}{1 - \frac{I_{xz}^2}{I_x I_z}}$$

Page 664

Figure 266, top of figure. Close the gap in the line under the "h".

Page 665

Fourth and fifth equations. Delete and substitute:

$$u_1 \propto \frac{200}{1 + (100 \quad)^2} \qquad (\text{ft/sec})^2 \text{ per rad/ft}$$

$$v_1 \propto \frac{939[1 + (400 \quad)]}{[1 + (1000 \quad)] [1 + (400 \quad /3^2} \qquad (\text{ft/sec})^2 \text{ per rad/ft}$$

Page 667

First and second sentence following third equation. Delete and substitute:

where: $_p$ = Ship pitch frequency, radians/second.

$_s$ = Ship pitch amplitude, radians.

Page 674

Table LVI, second column, fourth entry, line 4. Change to read: “components. High–frequency spectral”.

Page 680

4.9.3, first equation. Delete and substitute:

$$g \qquad q_g \qquad \frac{\partial w_g}{\partial x} \qquad p_g \qquad \frac{\partial w_g}{\partial y} \qquad r_g \qquad - \frac{\partial v_g}{\partial x}$$

Page 693

First row, fourth column. Change to read “iii, 1, 687”.

Second row, fourth column. Change to read “687”.

Page 701

Column heading, fourth column. Change to read “PAGE NO. IN THIS DOCUMENT”.

2. THE FOLLOWING PAGES OF MIL–STD–1797A HAVE BEEN REVISED AND SUPERSEDE THE PAGES LISTED:

NEW PAGE	DATE	SUPERSEDED PAGE	DATE
iii	30 January 1990	iii	REPRINTED WITHOUT CHANGE
iv – xiii	28 June 1995	iv – xxvii	30 January 1990
61	28 June 1995	61	REPRINTED WITHOUT CHANGE
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152 – 152d	28 June 1995	152	30 January 1990
267 – 275	28 June 1995	267–275	30 January 1990
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421	30 January 1990	421	REPRINTED WITHOUT CHANGE
422 – 422a	28 June 1995	422	30 January 1990
569	30 January 1990	569	REPRINTED WITHOUT CHANGE
570	28 June 1995	570	30 January 1990

3. RETAIN THIS NOTICE AND INSERT BEFORE TABLE OF CONTENTS.

4. Holders of MIL–STD–1797A will verify that corrections, page changes, and additions indicated above have been entered. This notice page will be retained as a check sheet. This issuance, together with appended pages, is a separate publication. Each notice is to be retained by stocking points until the military standard is completely revised or canceled.

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Army – AV
Navy – AS
Air Force – 11

Preparing Activity:
Air Force – 11

(Project 15GP–0111)

FOREWORD

This standard is intended for use with fixed–wing aircraft supported primarily by aerodynamic force rather than engine thrust. It also covers the handling characteristics of aircraft under piloted control on the ground, and may be used with powered–lift aircraft in aerodynamic flight (above the conversion speed, V_{con}). This standard also applies to piloted transatmospheric flight when flight depends upon aerodynamic lift and/or air breathing propulsion systems. Flying qualities of military rotorcraft are specified in MIL–H–850l, while flying qualities in V/STOL flight are the subject of MIL–F–83300.

For further background information, see Appendix C.

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TABLES

TABLES – Continued

AFFDL–TR–70–74 Vols I and II	An In–Flight Investigation to Develop Control System Design Criteria for Fighter Airplanes; Neal, T. P. and Rogers E. Smith, Dec 1970
AFFDL–TR–70–145	An In–Flight Investigation of Lateral–Directional Dynamics for the Landing Approach; Hall, G. W. and E. M. Boothe; Oct 1971
AFFDL–TR–70–155	Validation of the Flying Qualities Requirements of MIL–F–008785A(USAF); Brady, C. C. and J. Hodgkinson; Jan 1971
AFFDL–TR–71–134	Validation of the Flying Qualities Requirements of MIL–F–8785B(ASG); Kandalaft, R. N.; Sept 1971
AFFDL–TR–71–164 Vol I	In–Flight Investigation of an Unaugmented Class III Airplane in the Landing Approach Task. Phase I: Lateral–Directional Study; Wasserman, R., F. F. Eckhart and H. J. Ledder; Jan 1972
AFFDL–TR–72–36	Evaluation of Lateral–Directional Handling Qualities and Roll–Sideslip Coupling of Fighter Class Airplanes; Boothe, E. M. and M. L. Parrag; May 1972
AFFDL–TR–72–41	Revisions to MIL–F–8785B(ASG) Proposed by Cornell Aeronautical Laboratory Under Contract F33615–71–C–1254; Chalk, C. R., D. A. DiFranco, et al.; April 1973
AFFDL–TR–72–141 Vol I	Validation of the Flying Qualities Requirements of MIL–F–8785B(ASG) Using the P–3B Airplane; Richards, R. B., D. L. Green and J. C. Rennie; Nov 1973
AFFDL–TR–72–143	In–Flight Simulation of Minimum Longitudinal Stability for Large Delta–Wing Transports in Landing Approach and Touchdown. Vol I: Technical Results; Wasserman, R. and J. F. Mitchell; Feb 1973
AFFDL–TR–73–76	Recommended Revisions to Selected Portions of MIL–F–8785B(ASG) and Background Data; Ashkenas, I. L., R. H. Hoh and S. J. Craig; Aug 1973
AFFDL–TR–74–9	A Two–Phase Investigation]TJÈ1 10se TjÈ-1nal Flying Qualities for Fighters; Boothe, E. M., R. T. N. Chen and C. R. Chalk; April 1974
AFFDL–TR–74–61	Investigation]f Flying Qualities of Military Aircraft at High Angles of Attack. Vol I: Technical Results; Johnston, D. E., I. L. Ashkenas and J. R. Hogge; June 1974
AFFDL–TR–74–130 (2 Vols)	Extension]f the Method for Predicting Six–Degree–of–Freedom Store Separation Trajectories at Speeds Up to the Critical Speed to Include A Fuselage with Noncircular Cross Section; Dillenius, M. F. E., F. K. Goodwin and J. N. Nielsen; Nov 1974
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AFFDL–TR–77–34 Limited Flight Evaluation of Sidestick Controller Force–Deflection Characteristics on Aircraft Handling Qualities; Cima, William M., et al.; Nov 1977

AFFDL–TR–77–57 A Theory for Longitudinal Short–Period Pilot Induced Oscillations; Smith, Ralph H.; June 1977

AFFDL–TR–78–9 Fighter CCV Phase IV Report, Vol II: Flight Test Data Evaluation. Vol III: Test Phase Data Summary, Parts 1 and 2; McAllister, J. D., et al.; Feb 1978

AFFDL–TR–78–122 Effects of Control System Dynamics on Fighter Approach and Landing Longitudinal Flying Qualities (Volume I); Smith, Rogers E.; Mar 1978

AFFDL–TR–78–154 Handling Quality Requirements for Advanced Aircraft Design: Longitudinal Mode; Smith, Ralph H. and Norman D. Geddes; Aug 1979

AFFDL–TR–78–171 Proceedings of AFFDL Flying Qualities Symposium Held at Wright State University 12–15 September, 1978; Black, G. T., Moorhouse, D. J., et al., compilers; Dec 1978:

“Task–Oriented Flying Qualities for Air–to–Ground Gun Attack;” Brandeau, G.

“B–1 Experience Related to MIL–F–8785B and Proposed Revisions;” Campbell, J. E.

“An Approach to Simplify the Specification of Low–Speed Maneuvering Pitch Control Force;” Cichy, D. R.

“High Angle of Attack Flying Qualities and Departure Criteria Development;” Hellman, G. K. and R. B. Crombie

“Northrop Review of MIL–F–8785B Proposed Revision;” Lockenour, J.

“Evaluation of Selected Class III Requirements of MIL–F–8785B(ASG), ‘Flying Qualities of Piloted Airplanes;’” Withers, C. C.

“Discussion and Status of the Proposed Revision (1978) to MIL–F–8785B;” Moorhouse, D. J., R. J. Woodcock and T. P. Sweeney

AFFDL–TR–79–3126 Flight Qualities Design Requirements for Sidestick Controllers; Black, G. T. and D. J. Moorhouse; Oct 1979

AFWAL–TR–80–3032	Prediction of Supersonic Store Separation Characteristics Including Fuselage and Stores of Noncircular Cross Section (4 volumes); Goodwin, F. K., M. F. E. Dillenius and J. Mullen, Jr.; Nov 1980
AFWAL–TR–80–3060	Simulation Analysis: Unorthodox Control Force Fighter Aircraft, Vol II: Detailed Summary; Mitchell, A. L., et al.; Apr 1980
AFWAL–TR–80–3067	Flying Qualities Design Criteria: Proceedings of AFFDL Flying Qualities Symposium Held at Wright–Patterson Air Force Base in October 1979; Crombie, R. B. and D. J. Moorhouse, compilers; May 1980
AFWAL–TR–80–3141	Investigation of High–Angle–of–Attack Maneuvering – Limiting Factors, Part I: Analysis and Simulation; Johnston, D. E., D. G. Mitchell and T. T. Myers; Dec 1980
AFWAL–TR–81–3027	Development of Handling Quality Criteria for Aircraft with Independent Control of Six–Degrees–of–Freedom; Hoh, R. H., T. T. Myers, et al.; Apr 1981
AFWAL–TR–81–3090	Notes on Lateral–Directional Pilot Induced Oscillations; Smith, Ralph H.; Mar 1982
AFWAL–TR–81–3108	Investigation of High AOA Flying Qualities and Design Guides; Johnston, D. E. and R. K. Heffley; Dec 1981
AFWAL–TR–81–3109	Background Information and User Guide for MIL–F–8785C, Military Specification – Flying Qualities of Piloted Airplanes; Moorhouse, D. J. and R. J. Woodcock; Sept 1981
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30. DEFINITIONS

3.1 Aircraft classification and operational missions. For the purpose of this standard, the aircraft specified in this requirement is to accomplish the following missions: ____________. The aircraft thus specified will be a Class _____ aircraft. The letter –L following a class designation identifies an aircraft as land–based; carrier–based aircraft are similarly identified by –C. When no such differentiation is made in a requirement, the requirement applies to both land–based and carrier–based aircraft.

REQUIREMENT RATIONALE (3.1)

The very reason for procuring aircraft is to perform one or more missions. The class designation is used in the handbook to help particularize the requirements according to broad categories of intended use.

REQUIREMENT GUIDANCE

The related MIL–F–8785C paragraphs are 1.3, 1.3.1 and 3.1.1.

Missions

The standard needs a specific mission statement to furnish guidance for interpreting qualitative requirements as well as for consistent selection of quantitative requirements. Unfortunately, the word “mission” is used in several contexts not only in this standard, but throughout the writings pertinent to acquiring a new weapon system. In the broadest sense, “operational missions” applies to classifying the aircraft as fighter, bomber, reconnaissance, etc., or to “accomplishing the mission” of bombing, strafing, etc. In 3.1 the object is to introduce to the designer in general terms the function of the vehicle he is to design. It should be sufficient for the procuring activity to refer to those paragraphs of the System Specification and Air Vehicle Specification to define the overall performance requirements, the operational requirements, employment and deployment requirements.

The operational missions considered should not be based on just the design mission profiles. However, such profiles serve as a starting point for determining variations that might normally be expected in service, encompassing ranges of useful load, flight time, combat speed and altitude, in–flight refueling, etc., to define the entire spectrum of intended operational use. “Operational missions” include training and ferry missions.

The intended use of an aircraft must be known before the required configurations, loadings, and the Operational Flight Envelopes can be defined and the design of the aircraft to meet the requirements of this standard undertaken. If additional missions are foreseen at the time the detail specification is prepared, it is the responsibility of the procuring activity to define the operational requirements to include these missions. Examples of missions or capabilities that have been added later are in–flight refueling (tanker or receiver), aerial pickup and delivery, low–altitude penetration and weapon delivery, and ground attack for an air–superiority fighter or vice versa.

Once the intended uses or operational missions are defined, a Flight Phase analysis of each mission must be conducted. With the Flight Phases established, the configurations and loading states which will exist during each Phase can be defined. After the configuration and loading states have been defined for a given Flight Phase, Service and Permissible Flight Envelopes can be determined and Operational Flight Envelopes more fully defined.

4.1.6 Aircraft Normal States. The contractor shall define and tabulate all pertinent items to describe the Aircraft Normal States (no component or system failure) associated with each of the applicable Flight Phases. This tabulation shall be in the format and use the nomenclature of table II. Certain items, such as weight, moments of inertia, center–of–gravity position, wing sweep, or thrust setting may vary continuously over a range of values during a Flight Phase. The contractor shall replace this continuous variation by a limited number of values of the parameter in question which will be treated as specific States, and which include the most critical values and the extremes encountered during the Flight Phase in question.

REQUIREMENT RATIONALE (4.1.6)

Definition of normal aircraft states is basic to application of the flying qualities requirements.

REQUIREMENT GUIDANCE

The related MIL–F–8785C paragraphs are 3.1.6.1 and 4.2.

It is possible that items not normally considered, such as setting or automatic operation of engine bypass doors, can affect flying qualities.

The contractor is required to define the Aircraft Normal States for each applicable Flight Phase, in the format of table II. If the position of any particular design feature can affect flying qualities independently of the items in table II, its position should be tabulated as well. Initially, variable parameters should be presented in discrete steps small enough to allow accurate interpolation to find the most critical values or combinations for each requirement; then those critical cases should be added. As discussed under 4.1.1 through 4.1.3, center–of–gravity positions that can be attained only with prohibited, failed, or malfunctioning fuel sequencing need not be considered for Aircraft Normal States.

REQUIREMENT LESSONS LEARNED

5.1.6 Aircraft Normal States—verification. The contractor shall furnish a list of Aircraft Normal States in accordance with the Contract Data Requirements List.

VERIFICATION RATIONALE (5.1.6)

Definition of normal aircraft states is basic to application of the flying qualities requirements.

VERIFICATION GUIDANCE

Definition of normal aircraft states is basic to application of the flying qualities requirements.

VERIFICATION LESSONS LEARNED

4.1.6.1 Allowable Levels for Aircraft Normal States. Flying qualities for Aircraft Normal States within the Operational Flight Envelope shall be Level 1. Flying qualities for Aircraft Normal States within the Service Flight Envelope but outside the Operational Flight Envelope shall be Level 2 or better. To account for the natural degradation of pilot–vehicle performance and workload in intense atmospheric disturbances, the requirements of 4.1.6.1 through 4.1.6.3 are adjusted according to 4.9.1.

4.1.6.2 Flight outside the Service Flight Envelopes. From all points in the Permissible Flight Envelopes and outside the Service Flight Envelopes, it shall be possible readily and safely to return to the Service Flight Envelope without exceptional pilot skill or technique. The requirements on flight at high angle of attack, dive characteristics, dive recovery devices and dangerous flight conditions shall also apply in all pertinent parts of the Permissible Flight Envelopes.

4.1.6.3 Ground operation. Some requirements pertaining to taxiing, takeoffs, and landing involve operation outside the Operational, Service, and Permissible Flight Envelopes, as at V_S or on the ground. When requirements are stated at conditions such as these, the Levels shall be applied as if the conditions were in the Operational Flight Envelopes.

REQUIREMENT RATIONALE (4.1.6.1 – 4.1.6.3)

Levels of flying qualities as indicated in 3.3 apply generally within the Operational and Service Flight Envelopes. Some basic requirements, generally qualitative in nature, apply in both the Operational and Service Flight Envelopes. Provision must also be made for expected and allowable operation outside these envelopes.

REQUIREMENT GUIDANCE

The related MIL–F–8785C requirements are paragraphs 3.1.10, 3.1.10.1, 3.1.10.3.1, 3.1.10.3.2, 3.1.10.3.3, 3.8.3, and 3.8.3.1.

Aircraft Normal States include both all–up operation and degradations/failures that are sufficiently probable to be considered Normal. See 4.1.7 and 4.1.7.1 for guidance on the latter.

Note that flying qualities which “warrant improvement” according to figure 6 nevertheless meet all the requirements if they only occur outside the Operational Flight Envelope.

Where Levels are not specified, care should be taken in selecting requirements from this handbook that will not overburden the designer. We have tried to keep the impact of 4.1.6.1 in mind in writing the recommended material to fill in the blanks, but qualitative words such as “objectionable” must be taken in the context of relevance to operational use.

Since there are few requirements in Aircraft Failure States outside the Service Flight Envelope, implicit assumptions for 4.1.6.2 are that:

Failures at these conditions are very rare, or

Not–so–rare failures at these conditions are manageable

Given one or more failures within the Service Flight Envelope which would have serious consequences beyond, at a minimum the crew would be warned away from danger (4.1.8).

Similar assumptions apply for 4.1.6.3. In any given case, their validity will need to checked.

REQUIREMENT LESSONS LEARNED

5.1.6.1 Allowable Levels for Aircraft Normal States – verification. Verification shall be by analysis, simulation, and test. Final verification shall be by demonstration in the performance of the following tasks: ________.

5.1.6.2 Flight outside the Service Flight Envelopes – verification. Verification shall be by analysis, simulation and test. Final verification shall be by demonstration in the performance of the following tasks: ________________.

5.1.6.3 Ground operation – verification. Verification shall be by analysis, simulation and test. Final verification shall be by demonstration in the performance of the following tasks: ____________.

VERIFICATION RATIONALE (5.1.6.1 – 5.1.6.3)

Compliance with quantitative, open–loop (pilot–out–of–the–loop) requirements can be shown by analysis with data derived from flight test. However, compliance with only the quantitative, open–loop requirements does not guarantee that the required Levels of flying qualities have been achieved. The quantitative, open–loop requirements are based on historical data and research experiments with ground–based and in–flight simulators. Obviously, this data base has not evaluated each and every one of the infinite possible combinations of aircraft physical and dynamic characteristics at every possible flight condition in every possible task. The criteria in the quantitative, open–loop requirements are based on interpolation between and extrapolation beyond the configurations, flight conditions, and tasks that have been evaluated in the existing data base. Given the degree of generalization in this standard (all possible aircraft configurations generalized into four Classes, all possible tasks generalized into three Flight Phase Categories, and all possible flight conditions generalized into three Flight Envelopes) a certain amount of discrepancy between Level boundaries and pilot–observed flying qualities is to be expected occasionally. Furthermore, while the most significant factors affecting flying qualities have been identified and Level boundaries established for them, significant factor interactions, which have not been as well identified to date, may also cause discrepancies between Level boundaries and observed flying qualities. Other sources of such discrepancies are pilot and task variabilities. The pilots used to evaluate a configuration in a flight test program or a research experiment, and the levels of task performance required for desired and adequate ratings, will certainly skew the results. Therefore, in order to insure that the aircraft has achieved the required Levels of flying qualities, the aircraft must be evaluated by pilots in high–gain, closed–loop tasks. (In the context of this document, high–gain task means a wide–bandwidth task, and closed–loop means pilot–in–the–loop.) For the most part, these tasks must be performed in actual flight. However, for conditions which are considered too dangerous to attempt in actual flight (i.e., certain flight conditions outside of the Service Flight Envelope, flight in severe atmospheric disturbances, flight with certain Failure States and Special Failure States, etc.), the closed–loop evaluation tasks can be performed on a simulator.

During the requirements definition process, the procuring agency, together with the contractor(s) and the responsible test organization, should select several closed–loop tasks with which to evaluate the aircraft in flight test. During system development, ground–based and in–flight simulations should be used to get an initial appraisal of how well the aircraft will perform the tasks in flight. The simulations can also be used to train the test pilots and refine the tasks, performance objectives, and test procedures. Handling qualities evaluation during flight test should consist of four parts: 1) “open–loop” tasks such as steps, doublets, and frequency sweeps for parameter identification to compare aircraft dynamic response to the open–loop requirements, 2) capture tasks to familiarize the pilot with aircraft response and capture characteristics, 3) Handling Qualities During Tracking (HQDT) for initial closed–loop handling qualities evaluation, and 4) “operational” closed–loop tasks to obtain Cooper–Harper ratings. The distinction between HQDT and “operational” tasks is discussed in 5.1.11.6 Verification Guidance.

VERIFICATION GUIDANCE

A wide variety of closed–loop tasks have been developed for the evaluation of aircraft flying qualities. Recommended tasks for the evaluation of flying qualities for Flight Phase Category A include air–to–air and air–to–ground tracking, particularly the well–defined set of tasks known as HQDT, aerial refueling, close formation flying, and captures. Recommended tasks for the evaluation of flying qualities for Flight Phase Category C are tracking tasks, including HQDT, close formation flying, precision landings (with and without vertical and lateral offsets), takeoffs, and captures. More detailed discussions of each of these recommended tasks will be found in subsequent paragraphs of this section and 5.1.11.6 Verification Guidance. Other tasks which are critical to the mission that the aircraft is intended for may also be used as evaluation tasks, such as terrain–following, weapons delivery, or LAPES.

There are no recommended tasks for Flight Phase Category B because this Flight Phase Category generally consists of low–gain (low–bandwidth) tasks. Possible flying qualities problem in this Flight Phase Category will normally be exposed in the more demanding tasks for Flight Phase Categories A and C, and by normal operations during the flight test program. Thus, special tasks for this Flight Phase Category are not normally considered necessary. However, Flight Phase Category B tasks are normally of much longer duration than the tasks in the other Categories. Pilot fatigue may become a significant factor in certain mission critical Category B tasks, in which case an evaluation of this kind of task might be required.

Proof of compliance in these demonstration tasks will consist of pilot comments and Cooper–Harper (C–H) ratings. For Level 1, pilot comments must indicate satisfaction with aircraft flying qualities, with no worse than “mildly unpleasant” deficiencies, and median C–H ratings must be no worse than 3.5 in calm air or in light atmospheric disturbances. For Level 2, pilot comments must indicate that whatever deficiencies may exist, aircraft flying qualities are still acceptable, and median C–H ratings must be no worse than 6.5 in calm air or light atmospheric disturbances. For Level 3, pilot comments must indicate that the aircraft is at least controllable despite any flying qualities deficiencies, and median C–H ratings must be no worse than 9.5 in calm air or light atmospheric disturbances. In moderate to severe atmospheric disturbances pilot comments and C–H ratings must comply with the requirements of 4.9.1.

Actual task performance is not recommended for use as proof of compliance because it is even more subject to pilot variability than pilot comments and C–H ratings. The performance objectives suggested in the tasks described below are not intended for use as proof of compliance, but, rather, for use with the C–H scale. Specific definitions of desired and adequate performance objectives reduce pilot variability by insuring that all of the evaluation pilots attempt to achieve the same level of performance. In the performance objectives suggested below, adequate performance is set at a level sufficient to successfully perform similar tasks in operational service. Desired performance is set at a more demanding level to insure that system deficiencies are exposed. Although task performance is not recommended as proof of compliance, task performance should be recorded and analyzed by the flight test engineers to insure that pilot ratings are reasonably consistent with the level of performance achieved and that all pilots seem to be attempting to achieve the same level of performance.

The evaluation of aircraft flying qualities is basically a subjective science, and human variability makes analysis of the results a difficult proposition. Nevertheless, there are steps that can be taken to reduce variability in the results and insure a good evaluation. First of all, it is absolutely necessary that more than one evaluation be made for each test condition. Studies of inter–pilot C–H rating variability have indicated that three pilots is the minimum number of pilots for an adequate evaluation (CAL Report No. TB–1444–F–1 and NADC–85130–60). More pilots will increase confidence in the results, but NADC–85130–60 further demonstrated that the point of diminishing returns was reached at about six. Therefore, the recommended number of pilots per test condition is three to six. Careful selection of the evaluation pilots will also reduce the variability in results. All of the evaluation pilots must be test pilots trained in the use of the C–H scale and they all must be experienced in the Class of aircraft under evaluation. Furthermore, for acquisition purposes, it is highly desirable that at least half of the evaluation pilots be military–employed test pilots. (Use of operational pilots to evaluate the aircraft during the development effort can often provide additional insights into the handling qualities. Such evaluations are strongly encouraged. However, for the purpose of demonstrating compliance with this requirement, the evaluation pilots should be trained test pilots.)

In order to insure that all of the pilots attempt to achieve the same level of performance, and thus insure consistency and reduce the effects of pilot variability, it is extremely important to explicitly define the desired and adequate levels of task performance to be used for the C–H ratings. Best results are achieved with task performance defined in terms of quantifiable objectives which the pilot can readily observe himself in real time. Furthermore, consideration must be given to defining objectives that can also be recorded on some medium so that the flight test engineer can confirm that pilot ratings are reasonably consistent with task performance. Defining quantifiable and recordable task performance objectives and setting appropriate levels of desired and adequate performance is the most difficult part of planning the flying qualities evaluation. Guidance on task objectives for each of the recommended tasks is given in subsequent paragraphs in this section and lessons learned from past experience are provided in Verification Lessons Learned.

Another method to reduce the effects of variability is to use the “long–look” evaluation technique. In this technique the pilot continues or repeats the task until he is confident of his evaluation before he assigns a C–H rating. (As opposed to doing it once and assigning a rating.) The “long–look” approach allows the pilot a more extensive appraisal of the test condition, it allows him to weed out the effects of unique events in a single run, it allows him to get over the learning curve, and it allows him to clear his memory of characteristics he may have observed in evaluation of a preceding condition. Although the C–H rating is given only after multiple runs, pilot comments must be provided during and after each run. In order to insure that variability is not introduced by pilots doing different numbers of repeat runs, the recommended procedure is to specify a minimum number of runs to be performed before a rating can be given, and allow the pilot to make additional runs if he feels it is necessary.

Pilot comments should be considered the most important data. A C–H rating is only a summary of observed flying qualities characteristics into a single number. Pilot comments identify the specific deficiencies, if any, that must be corrected. Furthermore, the “long–look” technique filters the effects of deficiencies on the C–H rating because, over several runs, the pilot learns to compensate for some deficiencies. Since pilot comments are given for every run, the comments will identify all observed deficiencies, even those which can be compensated for. Comments on succeeding runs provide guidance on the pilot’s ability to compensate for the deficiencies and the final C–H rating indicates the relative significance of these deficiencies. Therefore, pilot comments must be recorded and analyzed for every test run.

Time and cost constraints prohibit piloted evaluation of every task in every possible aircraft configuration at every possible point in the flight envelope. The conditions that must be evaluated are the most common operating conditions, operating conditions critical to the mission of the aircraft, and the worst case conditions, especially those where the quantitative, open–loop flying qualities requirements are violated by wide margins. For aircraft with multiple flight control modes, all mode transitions should be evaluated at common, mission critical, and worst case conditions, especially mode switches which are done automatically, as opposed to those deliberately switched by the pilot. Furthermore, the degradation due to atmospheric disturbances should be demonstrated by evaluation at different levels of disturbances. Evaluation of the effect of severe atmospheric disturbances may be performed in ground simulation. When using simulation to predict the degradation of flying qualities due to severe atmospheric disturbances, it will be necessary to correlate C–H ratings gathered from simulation sessions in light to moderate turbulence with C–H ratings obtained from flight test in light to moderate turbulence for the same task.

The following paragraphs discuss some recommended tasks and some suggested performance objectives for each task. BEAR IN MIND THAT THE PERFORMANCE OBJECTIVES ARE NOT REQUIRED AS PROOF OF COMPLIANCE. THEY ARE INTENDED FOR USE WITH THE COOPER–HARPER SCALE TO REDUCE PILOT VARIABILITY. Most of these tasks are equally suitable for both the “operational” technique and the HQDT technique (see 5.1.11.6 Verification Guidance). The following list of tasks is not exclusive. Any closed–loop task, performed aggressively, may be used to evaluate an aircraft’s handling qualities and PIO characteristics. When developing a specification for a particular program, the procuring agency should discuss possible tasks and performance objectives with other procuring agencies, Wright Laboratory, AFFTC, and potential contractors.

Capture Tasks

Capture tasks are intended to evaluate handling qualities for gross acquisition as opposed to continuous tracking. A wide variety of captures can be done provided that the necessary cues are available to the pilot. Pitch attitude, bank angle, heading, flightpath angle, angle–of–attack, and g captures have all been done in previous programs to evaluate different aspects of the aircraft response. These capture tasks are done almost precognitively by the pilot and are usually over so quickly that they do not lend themselves well to use with the Cooper–Harper scale. It can be done, of course, but it is not necessary. Qualitative comments are sufficient proof of compliance for these tasks.

These capture tasks can give the pilot a general impression of the handling qualities of the aircraft, but because they do not involve closed–loop tracking they do not expose all of the problems that arise in continuous control tasks. Capture tasks should not be used as the only evaluation tasks. As a minimum, an offset precision landing task and some form of tracking task should also be used. Capture tasks are ideal as a pre–test before performing high–gain, closed–loop tasks because they serve to familiarize the pilot with the aircraft response before attempting the more difficult (and sometimes more dangerous) high–gain, closed–loop tasks. If hazardous motions result from the capture tasks at any flight condition, closed–loop tasks should not be attempted at that flight condition, and the aircraft should be considered to have failed this requirement at that condition.

For pitch captures, the aircraft is trimmed about a specified flight condition. The pilot aggressively captures 5′ pitch attitude (or 10′ if the aircraft is already trimmed above 5′). He then makes a series of aggressive pitch captures of 5′ increments in both directions. He then continues this procedure with 10′ increments in both directions, and then with 15′ increments in both directions. Aircraft with more capability can continue the procedure with larger pitch excursions. If possible, the initial conditions for each maneuver should be such that the aircraft will remain within ±1000 feet and ±10 knots of the specified flight condition during the maneuver, however, large angle captures at high–speed conditions will inevitably produce larger speed and altitude changes. If the aircraft should get too far from the specified condition during a task, it should be retrimmed about the specified condition before starting the next maneuver.

The other kinds of captures are usually done in a similar manner, with some minor differences. G captures are usually done from a constant–g turn and the increments are usually ±1g, ±2g, and ±3g, and larger increments if the aircraft has greater capability. Heading captures can be used to evaluate the yaw controller alone (usually small heading changes of 5′ or less) or to evaluate coordination of yaw and roll controllers (larger heading changes).

Bank angle captures are also commonly done using bank–to–bank rolls. Starting from a 15′ bank angle, the pilot aggressively rolls and captures the opposite 15′ bank angle (total bank angle change of 30′). He then rolls back and captures 15′ bank in the original direction. This procedure should continue for a few cycles. The procedure is then repeated using 30′ bank angles, and then repeated again using 45′ bank angles. Aircraft with more capability can continue the procedure with larger bank angles. A variation of this is to capture wings–level from the initial banked condition. Four–point and eight–point rolls, standard aerobatics maneuvers, are also good tests of roll control.

Air–to–Air Tracking

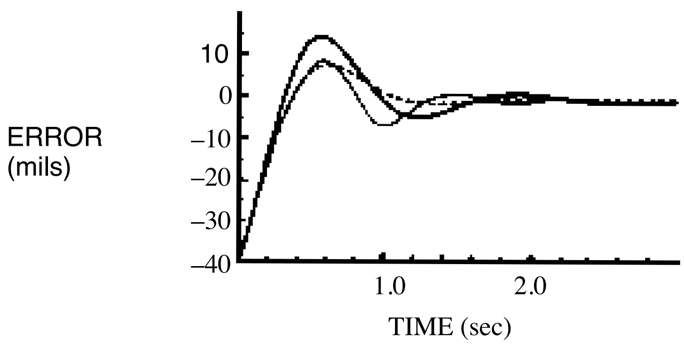
The air–to–air tracking task consists of two phases: gross acquisition and fine tracking. Gross acquisition evaluates the ability to point and capture with moderate–amplitude inputs. Fine tracking evaluates continuous closed–loop controllability. Two different kinds of targets have been used successfully in handling qualities evaluations: a real target aircraft and a target generated by a HUD (Head–Up Display).

If a real target is used, there are several possible target maneuvers which have been used in handling qualities evaluations in the past. In all cases the target aircraft begins the maneuver from straight and level flight in front of the evaluation aircraft at a specific flight condition. Throughout the maneuver the evaluation aircraft should remain within ≅1000 feet of the test altitude and within ≅50 knots of the test airspeed.

The maneuver most commonly used is an S–turn. The target aircraft initiates a level turn at a specified load factor. After a specified time period the target unloads, reverses, and begins a level turn in the opposite direction at the specified load factor. After a specified time period, the maneuver is terminated.

For gross acquisition, the evaluation pilot should allow the target aircraft to achieve a certain amount of angular displacement before he initiates his maneuver to acquire the target. Some programs have stated the angular displacement explicitly (for example, 100 mils or 30′). Other programs have used the point at which the target crosses the canopy bow to initiate gross acquisition. Yet another option is to allow a specified amount of time between the target aircraft turn and the evaluation aircraft turn (3–4 seconds). Commonly used performance objectives for gross acquisition are time to acquire, the number of overshoots, and the size of the overshoots. Acquisition is defined as bringing the pipper (or whatever the pilot is using to track with) within a certain radius of some specified point on the target (tail pipe, fuselage/wing junction, canopy, etc.). Time to acquire is the time it takes to bring the pipper within this radius and keep it there. Time to acquire is a difficult objective to recommend specific values for in a general standard because it is not only a function of handling qualities, but also a function of the size of the initial angular displacement between pipper and target point and of the maximum pitch rate performance of the aircraft under evaluation. Programs must consider both of these when determining what time to acquire to specify. An overshoot is when the pipper moves past the target point by some amount of angular displacement. Some suggested performance objectives are given in table LVIII.

An illustration of overshoot is shown in the sketch below, which shows time histories of three theoretical gross acquisitions. Assume the desired criteria are: no more than one overshoot greater than 5 mils and no overshoots greater than 10 mils. The thick continuous line would fail this criteria because it has one overshoot greater than 10 mils (at about 0.5 seconds). The thin continuous line also fails this criteria because it has two overshoots greater than 5 mils (around 0. 5 seconds and 0.9 seconds). The dashed line meets this criteria because it has only one overshoot that exceeds 5 mils but that overshoot is less than 10 mils.



For fine tracking, the time between reversals should allow for time to acquire plus time for extended tracking. A minimum of at least 20 seconds between reversals is recommended. The nominal range between the target aircraft and the evaluation aircraft should be about 1500 feet, with excursions of no more than ≅500 feet from nominal. The performance objective for fine tracking is to keep the pipper within a certain radius of the target point for a large percentage of the tracking time. Some suggested performance objectives are given in table LVIII.

For the long–look technique, this maneuver should be repeated a few times before giving a C–H rating. On a ground–based simulator the sequence of turns can continue uninterrupted until the evaluation pilot is confident that he has a good evaluation of the aircraft. This evaluation should be conducted at different airspeeds, different altitudes, and with different load factors throughout the Operational and Service Flight Envelopes.

Another common target maneuver is the wind–up turn. In the wind–up turn, the target aircraft begins a turn and slowly and smoothly increases the load factor to a specified maximum load factor. The target aircraft should attempt to maintain a specified rate of g increase, about .2 g/sec is recommended. The maneuver is terminated shortly after the maximum load factor is reached. Gross acquisition in this maneuver is similar to that for the S–turns. For fine tracking, the rate of g increase should allow sufficient time for gross acquisition and extended tracking time. For the long–look technique this maneuver should be repeated a few times. This evaluation maneuver should be initiated from various altitudes and airspeeds throughout the Operational and Service Flight Envelopes.

Other target–tracking maneuvers that have been used in the past are discussed in Verification Lessons Learned.

TABLE LVIII. Suggested performance objectives for various evaluation tasks.

Suggested Tasks	Suggested Performance Objectives
Air–to–Air and Air–to–Ground Tracking: Gross Acquisition	Desired Performance Time to acquire: TBD Overshoots: no more than one greater than 5 mils, none to exceed 10 mils No PIO
	Adequate Performance Time to acquire: TBD Overshoots: no ore than two greater than 5 mils, none to exceed 20 mils
Air–to–Air and Air–to–Ground Tracking: Fine Tracking	Desired Performance Keep the pipper within 5 mils of the target point for three continuous seconds No PIO
	Adequate Performance Keep the pipper within 10 mils of the target point for three continuous seconds
Close Formation	Desired Performance Excursions no greater than ≅2 feet from the formation position No PIO
	Adequate Performance Excursions no greater than ≅4 feet from the formation position
Aerial Refueling: Boom Tracking	Desired Performance Keep pipper within 5 mils of the boom nozzle for at least 50% of the tracking time No PIO
	Adequate Performance Keep pipper within 10 mils of the boom nozzle for at least 50% of the tracking time
Aerial Refueling: Probe–and–drogue	Desired Performance Hook–up without touching basket webbing in at least 50% of the attempts No PIO
	Adequate Performance Hook–up in at least 50% of attempts
Offset Precision Landing: Approach	Desired Performance Flightpath control: Remain within ≅1 degree of glideslope angle or ≅$^1/_2$ dot on ILS Airspeed control: Maximum of 5 knots above approach speed, minimum TBD No PIO
	Adequate Performance Flightpath control: Remain within ≅2 degrees of glideslope angle of ≅1 dot on ILS Airspeed control: Maximum of 10 knots above approach speed, minimum TBD, but not less than V_{stall}

TABLE LVIII. Suggested performance objectives for various evaluation tasks – Cont'd.

Suggested Tasks	Suggested Performance Objectives
Offset Precision Landing: Touchdown (Conventional aircraft)	Desired Performance Touchdown zone: within ≅25 feet of aimpoint laterally, within –100 to +400 feet of aimpoint longitudinally Speed at touchdown: maximum of 5 knots above landing speed, minimum TBD Attitude at touchdown: TBD Sink rate at touchdown: TBD No PIO
	Adequate Performance Touchdown zone: within ≅50 feet of aimpoint laterally, within –250 to + 750 feet of aimpoint longitudinally Speed at touchdown: maximum of 10 knots above landing speed, minimum TBD Attitude at touchdown: TBD Sink rate at touchdown: TBD
Offset Precision Landing: Touchdown (STOL aircraft)	Desired Performance Touchdown zone: within ≅10 feet of aimpoint laterally, within –25 to +75 feet of aimpoint longitudinally Speed at touchdown: maximum of 2 knots above landing speed, minimum TBD Attitude at touchdown: TBD Sink rate at touchdown: TBD No PIO
	Adequate Performance Touchdown zone: within ≅25 feet of aimpoint laterally, within –100 to +400 feet of aimpoint longitudinally Speed at touchdown: maximum of 5 knots above landing speed, minimum TBD Attitude at touchdown: TBD Sink rate at touchdown: TBD
Offset Precision Landing: Rollout and Takeoff Roll	Desired Performance Keep the nosewheel within ≅10 feet of the runway centerline No PIO
	Adequate Performance Keep the nosewheel within ≅25 feet of the runway centerline
Takeoff Rotation	Desired Performance Attitude control: Keep within ≅1 degree of takeoff attitude Overshoots: no more than one overshoot, not to exceed TBD degrees No PIO
	Adequate Performance Attitude control: Keep within ≅2 degrees of takeoff attitude Overshoots: no more than one overshoot, not to exceed TBD degrees

TABLE LVIII. Suggested performance objectives for various evaluation tasks – Cont'd.

Suggested Tasks	Suggested Performance Objectives
Takeoff Climbout	Desired Performance Flightpath control: Keep within ≅1 degree of specified climbout angle Groundtrack: Keep aircraft within ≅10 feet of runway centerline or within ≅2 degrees of runway heading No PIO
	Adequate Performance Flightpath control: Keep within ≅2 degrees of specified climbout angle, but not less than 0′ Groundtrack: Keep aircraft within ≅25 feet of runway centerline or within ≅5 degrees of runway heading

An alternative to using a real target aircraft is to do a HUD tracking task. In this task, a target symbol (tracking bars or a line–drawing of a target) is projected on the HUD which commands pitch and roll changes that the evaluation pilot must follow. The pitch and roll commands can be combinations of steps and ramps, a smoothly–varying function (such as a sum–of–sines), or a simulated target aircraft maneuver (such as those described above) . The sequence of pitch and roll commands should be designed so as to keep the aircraft within ≅1000 feet of the test altitude and within ≅50 knots of the test airspeed. The sequence should be long enough and complex enough that the pilot cannot learn to anticipate the commands. Some example sequences that have been used before are discussed in Verification Lessons Learned.

Air–to–Ground Tracking

The air–to–ground tracking task has two phases: gross acquisition and fine tracking. Gross acquisition evaluates the ability to switch from one target to another. Fine tracking evaluates the ability to continuously track a target.

For this task, the aircraft flies at a specified glideslope and airspeed toward a group of widely–spaced targets on the ground. The airspeed and glideslope should be representative of the intended operational application for the aircraft. Initial range to the targets should allow time for acquisition and tracking of several targets. The targets should be from 60 to 180 feet apart perpendicular to the flight path and anywhere from 90 to 360 feet apart parallel to the flight path. The pilot aggressively captures the first target and tracks it for a specified period of time (4 seconds is recommended), and then acquires and tracks succeeding targets. The sequence of targets to be tracked should be specified in advance. As the aircraft approaches the targets the angular displacement between the targets will increase. Therefore, at long range the sequence should require switching between the more widely–spaced targets (from one end of the group to the other end, for example). As the range closes the sequence should require switching between targets which are closer together (adjacent targets). The last target switch should require a pitch up. A minimum recovery altitude should be specified at which the pilot must abandon the task. This minimum altitude should consider the airspeed and dive angle of the task and should allow plenty of margin for the pilot to pull out. Suggested performance objectives are the same as those for air–to–air tracking. Some suggested performance objectives are given in table LVIII.

Close Formation Task

While the tracking tasks put a lot of emphasis on attitude control, close formation tasks put more emphasis on flight path control. The task consists of holding close formation with a target aircraft as it maneuvers. Both wing and trail formations are used. The performance objective is to maintain relative position between the target aircraft and the aircraft under evaluation. Specific objectives are difficult to recommend because the pilot usually uses visual alignment of some part of his aircraft against the target aircraft to gauge his position, and, of course, this will vary with evaluation aircraft and target aircraft. Some suggested displacements to use for performance objectives are given in table LVIII, however, consideration should be given to the nature of the target maneuvers. More relaxed performance objectives should be used for the more extreme target maneuvers. A procuring agency will have to determine for themselves what these numbers mean in terms of visual alignment with the target aircraft in their program.

The target maneuvers used in this task are usually the same or similar to the ones used in the air–to–air tracking task, including the ones mentioned in Verification Lessons Learned. For the long–look technique the task should be done a few times in the wing formation and then done a few times in trail formation and then rated. The pilot's objectives in this task are outside visual references which are difficult to gauge and are usually not recorded by any medium (unless a video camera is specially mounted for this task or an observer is carried in one of the aircraft).

Aerial Refueling

There are two types of aerial refueling: probe–and–drogue and flying boom. To date, evaluation tasks associated with both types of aerial refueling have not been formalized as much as those for tracking and precision landing tasks. Some formalized tasks which have been used in previous programs are described below.

For boom–type aerial refueling, the most frequently used evaluation task is some type of boom tracking task. Two approaches have been tried. The first approach is to track the nozzle of the boom with a waterline symbol or a pipper on the HUD or windscreen. The evaluation aircraft takes station in the pre–contact position about 50 feet aft and down on a 30 deg line from the tanker, which maintains steady, level flight with the boom extended. The boom may be held stationary or moved around slowly (no more than 1 deg/sec). The tracking time should be extensive for a good evaluation: two to four minutes is recommended. The performance objective is to keep the pipper or waterline symbol within a certain radius of the nozzle of the boom for a large percentage of the tracking time. Some suggested performance objectives for this approach are given in table LVIII.

In the second approach the evaluation pilot attempts to keep the end of the boom visually aligned with some point on the tanker aircraft. The evaluation aircraft maintains the pre–contact position within about $\cong$ 10 feet. In this approach the boom is held stationary. The recommended tracking time is two to four minutes. The performance objective in this approach is to keep the end of the boom visually aligned within a clearly discernible area on the tanker for a specified percentage of the tracking time. It is difficult to recommend performance objectives for this approach because they will depend on the type of tanker in use. However, an example of a project which used this approach with a KC–135 is given in Verification Lessons Learned.

For probe–and–drogue refueling actual hook–ups have been used as evaluation tasks. In one such program, the performance objective was the ratio of successful hook–ups to attempted hook–ups. The task starts from the standard pre–contact position. When cleared for contact, the evaluation pilot establishes a 3–5 knot closure rate towards the drogue and attempts to make contact. If the drogue is successfully engaged, the evaluation pilot stabilizes for approximately 30 seconds, and then establishes a 3–5 knot separation rate to disconnect and return to the pre–contact position. If the closure rate exceeds 5 knots, the probe tip passes the outside edge of the drogue basket, the probe tips the basket, or if a hazardous situation develops, the hook–up attempt is aborted and the evaluation pilot returns to the pre–contact position before making another attempt. The performance objective is a certain percentage of successful hook–ups out of a specific number of attempts. Six to twelve is the recommended number of attempts. Some suggested performance objectives are given in table LVIII.

Offset Precision Landing

The standard evaluation task for approach and landing is an offset precision landing. There are up to three phases in this task: approach, touchdown, and, sometimes, rollout. The approach phase evaluates the ability to control flightpath, airspeed, and attitude, including gear–down transients and large amplitude maneuvers. The touchdown phase evaluates the ability to control flightpath, airspeed, and attitude to a precise touchdown in the presence of ground effects and through touchdown transients. Rollout evaluates ground handling after touchdown.

The approach phase evaluation begins about a mile out on final approach, with gear and flaps up, at the required glideslope angle, but with a lateral offset from the runway centerline of about 150 to 300 feet, and a vertical offset from the glideslope of about 100 to 200 feet. Soon after the task begins the pilot lowers gear and flaps to the landing configuration. The pilot maintains precise flightpath angle and airspeed control throughout the approach phase up to the offset correction point. Some suggested performance objectives are given in table LVIII. Determination of performance objectives for flight path control should consider what cues are available to the pilot. Determination of performance objectives for airspeed control must consider the margin between the recommended approach speed and V_{stall}.

Lateral offsets of 200 feet or less should be corrected at 150 feet AGL. Lateral offsets of more than 200 feet should be corrected at 200 feet AGL. The pilot should make an aggressive correction to the glideslope. The correction should be completed with the wings approximately level by 50 feet AGL to avoid the possibility of striking the ground.

The touchdown phase begins at about 50 feet AGL. The pilot attempts to put the main wheels down inside a designated touchdown zone at a specified landing speed, attitude, and sink rate. The landing zone should be clearly identifiable on the runway. Performance objectives are the touchdown location, landing speed, attitude, and sink rate at touchdown. Some suggested performance objectives for conventional aircraft are given in table LVIII. Determination of performance objectives for airspeed control must consider the margin between the recommended landing speed and V_{stall}. Similarly, performance objectives for attitude at touchdown must consider aircraft geometry (to preclude wingtip or tail strikes, etc.) and landing gear limitations (side force limits, etc.). Landing gear limitations must also be considered in the determination of performance objectives for sink rate at touchdown.

Performance objectives for STOL and carrier–based aircraft should be more demanding. Suggested performance objectives for STOL aircraft are also given in table LVIII.

The rollout phase begins after touchdown. The pilot steers from the touchdown point to the runway centerline and thereafter stays on the runway centerline while bringing the aircraft to a stop. For STOL aircraft a stopping distance should be specified (usually set by mission performance requirements). Some suggested performance objectives are given in table LVIII. Landing rollout should be evaluated with and without crosswinds using rudder and nosewheel steering or differential braking. Landing rollout might also be evaluated under various runway conditions (dry, wet, icy, patched, etc.) . Ground handling qualities should be expected to degrade with degraded runway conditions in a similar manner to the way handling qualities degrade with atmospheric disturbances, however, at this time there is no available guidance on how much degradation to allow under various runway conditions. The best that can be said at this time is that ground handling should be Level 1 for normal runway conditions, and if the aircraft cannot be kept on the runway under certain conditions, the aircraft should be considered uncontrollable for those conditions. As is the case in evaluations with atmospheric disturbances, dangerous runway conditions should only be tested in ground simulation.

In flight test, bringing the aircraft to a full stop on the runway on every run is inadvisable due to cost and time constraints. Therefore, for the long–look technique, approach and touchdown should be evaluated by doing a few touch–and–goes before giving a C–H rating. Rollout should be evaluated on the last landing, which is brought to a complete stop. On a ground–based simulator, the aircraft should be brought to a stop every time. On ground–based simulators, pilots tend to be "lower gain" than they are in flight. To counter this, light random turbulence and fairly large discrete gusts should be introduced throughout the task. In particular, a discrete gust should be introduced after the offset correction. Degradation with atmospheric disturbances (4.9.1) should be evaluated by increasing the turbulence and the gusts and by adding crosswinds and wind shears.

Because this task is done in close proximity to the ground it should not be attempted if other evaluations (analysis, ground simulation, or flight test) indicate a high probability of Level 3 handling qualities or hazardous PIO tendencies. Therefore offset precision landing tasks should be performed on a ground–based simulator and approach handling qualities should be evaluated with other in–flight tasks (such as HQDT) before attempting actual offset precision landings in flight test. Obviously, if this task is considered too dangerous to attempt, the aircraft is considered to have failed this requirement.

Takeoff

Takeoff tasks have not been done as often as landing and tracking tasks, so there is little practical experience on which to base the task recommended here. The task consists of three phases: takeoff roll, rotation, and climb–out. The takeoff roll evaluates ground handling from brake release to takeoff rotation. The rotation phase evaluates ability to control attitude during takeoff. The climb–out phase evaluates ability to control flightpath after takeoff, including leaving ground effect and gear transients.

The takeoff roll begins from takeoff condition at the end of the runway. The pilot advances the throttles to a specified setting and releases the brakes. The task is to track the runway centerline as the aircraft accelerates. The suggested performance objectives for this phase are the same as those for landing rollout. Some suggested performance objectives for the takeoff roll are given in table LVIII.

At a specified speed the pilot briskly rotates the aircraft to takeoff attitude. Performance objectives in this phase are attitude control, number of overshoots, and size of overshoots. An overshoot in this case is defined as any deviation above the specified takeoff attitude. The purpose of the overshoot limit is to prohibit over–rotation. Some suggested performance objectives for takeoff rotation are given in table LVIII. Determination of performance objectives for overshoot are dependent on aircraft geometry and the recommended takeoff attitude.

After main wheel liftoff, the pilot maintains a specific flightpath angle and groundtrack. He maintains this flightpath until the landing gear has been retracted and all transients have settled out. Some suggested performance objectives for takeoff climbout are given in table LVIII. Determination of performance objectives for flightpath control should consider what cues are available to the pilot. In most cases pitch attitude is used as a substitute when flightpath angle is not an available cue. The tolerance for adequate flightpath control should not allow a negative flightpath angle. For groundtrack control, heading angle may be used as a substitute for deviation from runway centerline.

It would be impractical to evaluate takeoff roll with a long–look technique in flight test because the aircraft would have to land and taxi back to the end of the runway each time. However, rotation and climb–out could be evaluated with a long–look technique by doing touch–and–goes. On a ground–based simulator the entire task could be done using a long–look technique. As with the landing tasks, light random turbulence and moderate discrete gusts should be used to increase the pilot's "gain" on a ground–based simulator. Degradation with atmospheric disturbances (4.9.1) can be evaluated on the ground simulator by increasing the turbulence and gusts and by adding crosswinds and wind shears.

VERIFICATION LESSONS LEARNED

An important source of guidelines on the use of tracking techniques for handling qualities evaluation is AFFTC–TD–75–1. AFFTC–TD–75–1 discusses execution and analysis of results of both air–to–air and air–to–ground tracking techniques. Many of the recommendations in AFFTC–TD–75–1 are also applicable to other closed–loop handling qualities evaluation techniques. Further discussions of the design and conduct of handling qualities testing and the use of the Cooper–Harper scale can be found in CAL Report TB–1444–F–1, NADC–85130–60, NASA TN D–5153, AIAA 89–3358, and AIAA 90–2822.

Some of the. most detailed descriptions of closed–loop evaluation tasks which have been used in the past can be found in USAFTPS and AFFTC handling qualities test plans and flight test reports. Descriptions of several tasks taken from USAFTPS Letter Reports can be found in AFFDL–TR–77–34 and AFFDL–TR–79–3126. AFFTC handling qualities reports which contain descriptions of several closed–loop evaluation tasks include AFFTC–TR–75–15 (the YF–16), AFFTC–TR–77–11 (the A–10), AFFTC–TR–77–23 (the YF–16 Control Configured Vehicle (CCV)), AFFTC–TR–83–45 (the Advanced Fighter Technology Integration AFTI/F–16), and AFFTC–TR–91–29 (the F–15 STOL and Maneuver Technology Demonstrator (S/MTD)).

Another source of closed–loop evaluation tasks is the Standard Evaluation Maneuver Set (STEMS). The results of this project are documented in WL–TR–93–3081, WL–TR–93–3082, and WL–TR–93–3083. The main products of this project were: 1) a process to develop handling qualities evaluation maneuvers, 2) an initial set of 20 evaluation maneuvers tested in ground simulation, and 3) guidelines to help users select appropriate maneuvers. WL–TR–93–3081 describes the maneuver development process. WL–TR–93–3082 provides descriptions of the initial set of evaluation maneuvers and a selection guide. WL–TR–93–3083 documents the results of the ground simulation tests of the initial maneuver set. The maneuvers developed in this project were primarily aimed at evaluation of agility and high–angle–of–attack flying qualities, however, there were some conventional flying qualities evaluation maneuvers as well. AIAA–93–3645 provides a summary of the STEMS project.

Air–to–Air Tracking

Air–to–air tracking is one of the most commonly used handling qualities evaluation techniques. Examples of the use of this kind of task can be found in many handling qualities reports. The task descriptions and performance objectives recommended in Verification Guidance stem largely from numerous USAFTPS projects conducted in the mid–1970s to the early 1980s using the variable–stability NT–33A. The task descriptions in these projects remained fairly similar throughout this period and are documented in AFFDL–TR–77–34 and AFFDL–TR–79–3126. In the earliest of these tests the performance objectives for Cooper–Harper ratings were undefined. The performance objectives gradually became better defined with succeeding projects. The performance objectives suggested in Verification Guidance reflect the objectives used in the later projects. Similar performance objectives were used on McDonnell–Douglas and Wright Laboratory ground simulators during the development of the F–15 S/MTD (WRDC–TR–89–3036).

Some other target maneuvers which have been used in air–to–air tracking are a modified Lazy–Eight maneuver, a constant–g barrel roll, and an unpredictable target maneuver. Discussions of the use of the modified Lazy–Eight and the barrel roll maneuver can be found in AFFDL–TR–79–3126. The unpredictable target is a target which is free to maneuver within certain restrictions. Normally, it is restricted in airspeed (typically within $\cong$50 knots of test condition), altitude (typically within $\cong$1000 feet of test condition), load factor, and onset rate (typically restricted to no more than .5 g/sec).

One of the conventional evaluation tasks of the STEMS project was Tracking in Power Approach. The task was to track a target aircraft from approximately 1500 ft range in power approach configuration at approach airspeed. The target performed gradual S–turns with periods of straight flight between turns. Constant altitude was maintained during the maneuver. The evaluation pilot selected specific aim points on the target and tracked them during the maneuver. In the simulation, different target profiles were required for different Classes of aircraft. For fighter aircraft, the target performed a 30′ heading change every 20 seconds. For transport aircraft, a 15′ heading change was performed every 15 seconds. Desired performance was to keep the pipper within $\cong$5 mils of the aim point for 50% of the task and within $\cong$25 mils for the remainder of the task, with no PIO. Adequate performance was to keep the pipper within ≅ 5 mils of the aim point for 10% of the task and within ≅ 25 mils for the remainder of the task. This maneuver can be performed at a safe altitude before attempting precision landings.

HUD tracking tasks have been used in a number of handling qualities research programs. Some example step–and–ramp tracking sequences are shown on figure 273. The sequences shown in a) and b) are pitch tracking sequences that were used on the NT–33A in USAFTPS projects (USAFTPS Report 82B–4). The two sequences shown in c) are a combined pitch and roll tracking sequence used on the NT–33A and on Calspan's variable–stability LearJet in many recent projects (Calspan Report No. 7738–24). Another type of sequence in use is a sum–of–sines. This is a frequency–based function driven by an equation such as:

$$\Delta_c = K \sum_{i=1}^{n} A_i \sin(\beta_i\, t + ._i)$$

where Δ_c = the commanded pitch attitude (or bank angle)

K = the task gain

n = the number of sine waves

A_i = the amplitude of each sine wave

β_i ” the frequency of each sine wave

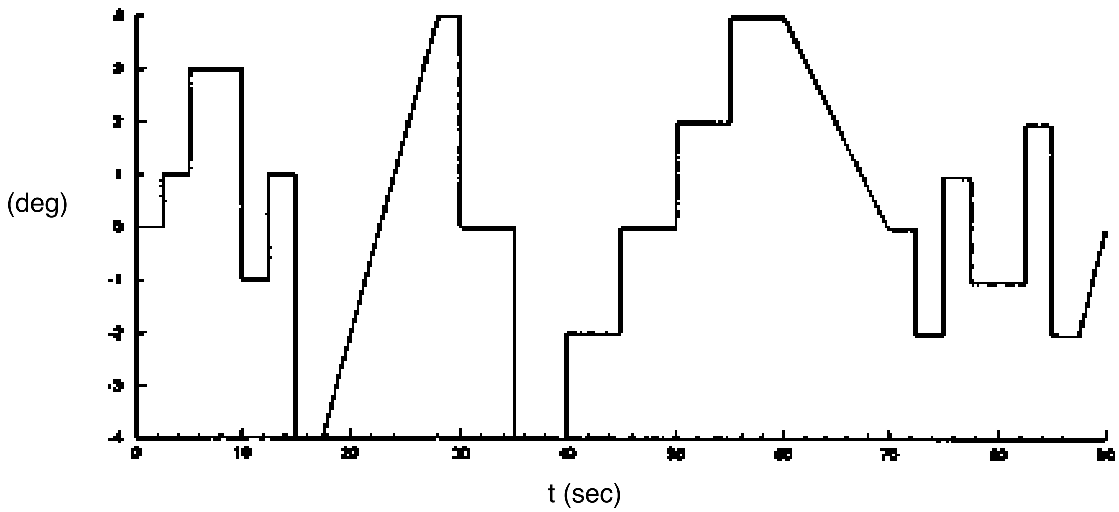
$._i$ = the phase of each sine wave

Such a function was used in a project on the LearJet (AFFTC–TLR–93–41) using 13 sine waves evenly spaced in frequency between 0.1 and 30 rad/sec. The HUD symbology usually used in HUD tracking tasks are tracking bars, but with the computational power and electronic displays available today, it is worth considering special flight test software to provide a more definitive target.

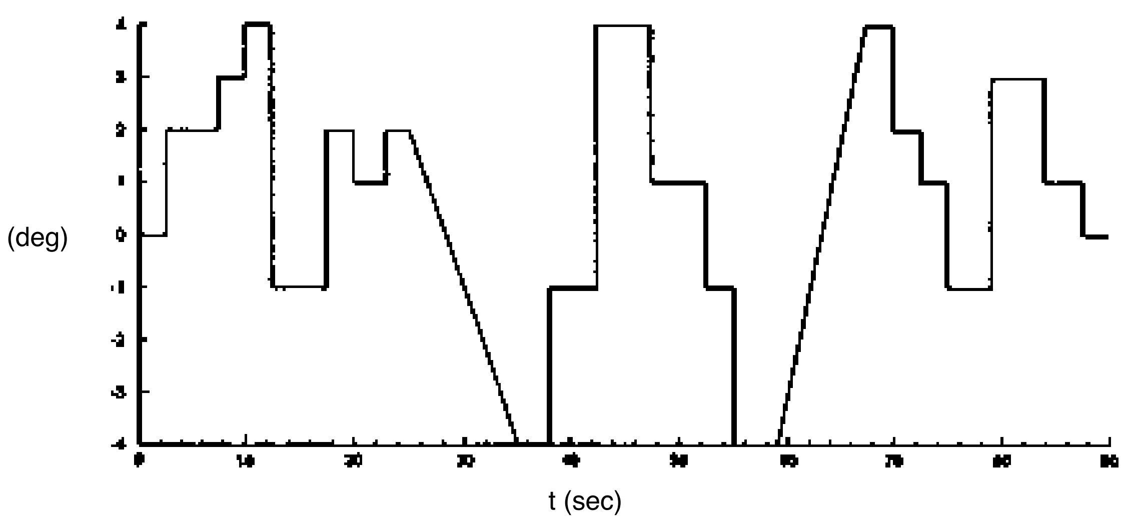
One advantage of HUD tracking tasks is that, if the HUD update rate and HUD dynamic characteristics are duplicated in the simulators, the task itself can be identical between ground simulation, in–flight simulation, and flight test, providing a greater degree of commonality between these three stages of evaluation. Bear in mind, though, that HUD dynamic characteristics will affect handling qualities more in these tasks than in tasks such as formation flying or VFR landings.

Air–to–Ground Tracking

Previous flight test programs which have used air–to–ground tracking techniques include the A–10 (AFFTC–TR–77–11 and Brandeau, AFFDL–TR–78–171), YF–16 CCV (AFFTC–TR–77–23), and AFTI/F–16 (AFFTC–TR–83–45). A very promising system for an air–to–ground tracking task called GRATE (Ground Attack Targeting Equipment) was developed and tested by the Deutsche Forschungs–und Versuchsanstalt fur Luft–und Raumfahrt (DFVLR) in the 1980s (Koehler, NASA CP 2428 and Koehler, AGARD–CP–452). This task used a pattern of lights on the ground as a target. The pilot acquires and tracks each light in turn as the lights are illuminated in a specific sequence. The Germans evaluated this task with an AlphaJet with great success. The task was also subsequently used successfully on a ground–based simulator (Biezad, AFWAL–TR–86–3093). In 1987 the Dryden Flight Research Center (DFRC) developed a derivative system known as the Adaptable Target Lighting Array System (ATLAS). This system has been tested with the NT–33 (USAFTPS–TR–88A–TM1), the X–29 (NASA TM 101700), and the F–15 S/MTD. An example of a typical ATLAS array is shown on figure 274. The ATLAS system is currently operational at DFRC at Edwards AFB.

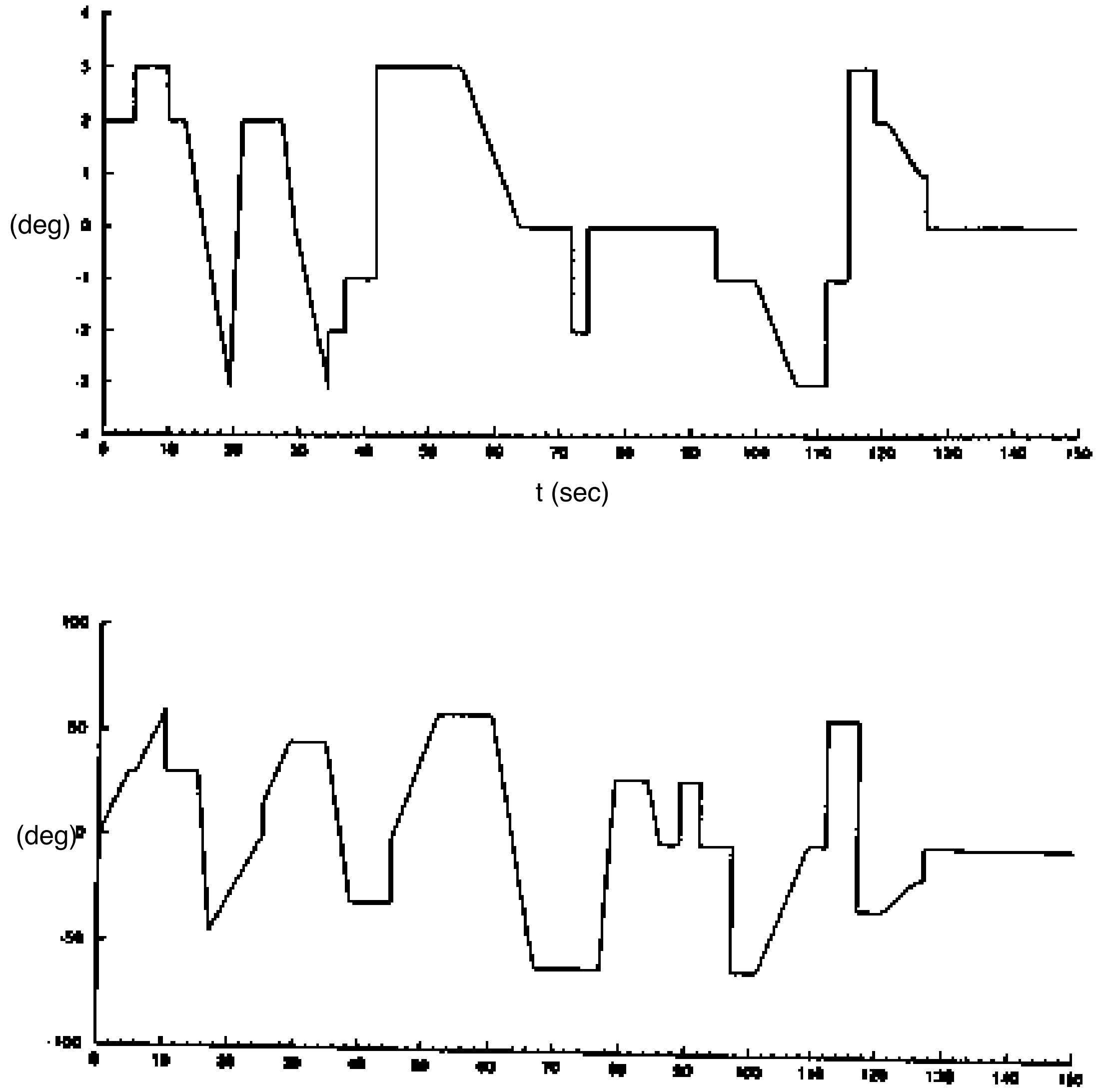


a) Pitch tracking task



b) Pitch tracking task

FIGURE 273. Example step–and–ramp HUD tracking sequences.



c) Combined pitch and roll tracking task

FIGURE 273. Example step–and–ramp HUD tracking sequences – continued.

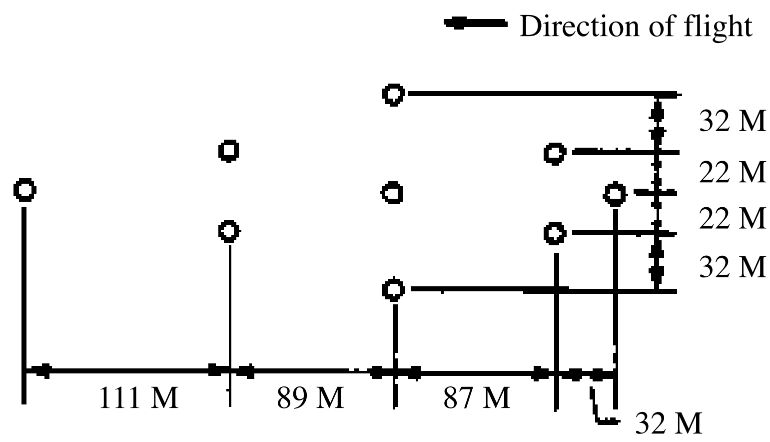


FIGURE 274. Typical ATLAS light pattern (from NASA TM 101700).

Close Formation Task

Formation flying tasks were used in the evaluations of the YF–16 CCV (AFFTC–TR–77–23), the AFTI/F–16 (AFFTC–TR–83–45), and the F–15 S/MTD (AFFTC–TR–91–29 and WL–TR–92–3027). The YF–16 CCV evaluation included station keeping and position changes during straight and level flight and in “mild to moderate” lazy–eight maneuvers. Vertical and horizontal position changes of 500 feet and 50 feet were made.

AFTI/F–16 formation tasks were done in close trail and wingtip positions. The following descriptions are taken from AFFTC–TR–83–45.

> “The close trail evaluations were conducted with the AFTI/F–16 in a position ten feet below the lead aircraft with zero to ten feet nose–to–tail separation. The lead aircraft flew between 250 to 300 KCAS while making gentle maneuvers. This maneuvering included bank angle variations up to 30 degrees and gentle climbs and descents.”

> “The close formation evaluations were conducted with the AFTI/F–16 in a tight position off the wing of the lead aircraft. After a reasonable buildup, the AFTI/F–16 pilot flew as close to the lead aircraft as was comfortable. The lead aircraft flew either in level flight or through a series of lazy eight maneuvers. Bank angle changes ranged between ±90 degrees, pitch attitude ranged between ≅45 degrees, airspeed between 200 and 500 KCAS and load factor between one and five g’s. In this task the pilots attempted to maintain a precise position relative to the lead aircraft using fingertip formation techniques. The AFTI/F–16 would intentionally make lateral and vertical deviations in order to evaluate the aircraft’s ability to return to the nominal position.”

In the F–15 S/MTD program a formation task was used to evaluate PIO tendencies in power approach. The pilot attempted to maintain formation with an A–37 while the A–37 performed random 0.25–g step inputs (three to five foot vertical variations).

Aerial Refueling

Boom tracking with a HUD pipper or a waterline symbol has been done in several programs at AFFTC. In every case, however, it was done using the HQDT technique (described in 5.1.11.6 Verification Guidance), where the objective was zero pipper error. At this time there is no data to support the suggested performance objectives for this task other than the fact that these objectives have been successfully applied in other kinds of tracking tasks.

Boom tracking using visual alignment with the tanker was proposed as a handling qualities task by the 4950th Test Wing in a flight test project to develop an aerial refueling evaluation task for Class III aircraft. The tanker aircraft in their project was a KC–135. The visual desired zone for their task was between the rivet lines on the bottom of the KC–135. The adequate zone was the edges of the fuselage. A diagram of these zones is shown in Figure 275. In the test they used two different evaluation aircraft: a C–135 and a C–18. The performance objective was the cumulative time the evaluation pilot could keep the boom nozzle aligned within the desired zone during two minutes of tracking. Four different levels of desired performance were tested: 30 seconds, 45 seconds, 60 seconds, and 75 seconds. Adequate performance was defined as keeping the nozzle within the adequate zone for the entire 2 minutes. Unfortunately, the pilots considered both aircraft Level 2 for this task because of the amount of compensation required. The results for all four levels of desired performance gave Level 2 C–H ratings for both aircraft, thus the C–H ratings give no indication of which is the best value to use for desired performance. The results do lend credence to their choice of adequate criteria, but this was not a variable in the test. Nevertheless, based on the performance achieved with both aircraft throughout the project, the pilot consensus was that 60 seconds in the defined desired zone (or about 50% of the tracking time) was “both attainable and realistic” and that the task was demanding enough to expose undesirable handling qualities. This project was documented in 4950–FTR–93–05.

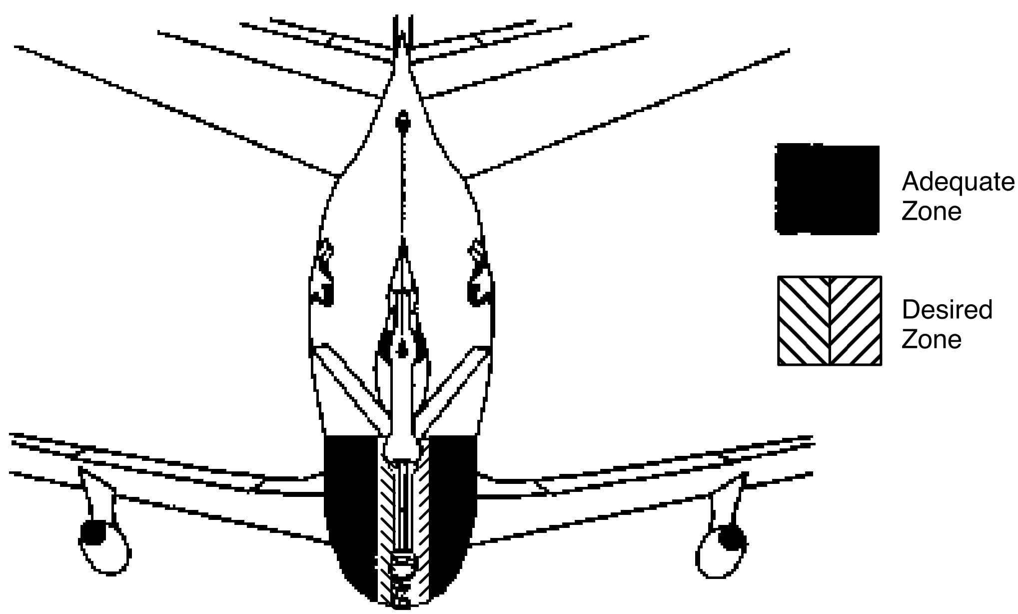


FIGURE 275. Adequate and desired performance for 4950th boom tracking task (from 4950–FTR–93–05).

The STEMS project also tested a boom tracking task. The task was to track the refueling probe of a tanker from the pre–contact position. The evaluation pilot can track a steady probe, periodically changing aim points on the boom (such as the boom wingtips), or the boom operator can make small random horizontal and vertical movements with the boom to create tracking errors. Desired performance in the STEMS project was to maintain the aim point within a 30–mil radius of the pipper for at least 50% of the task, with no objectionable PIOs. Adequate performance was to maintain the aim point within a 50–mil radius of the pipper for at least 50% of the task.

Probe–and–drogue refueling was used as an evaluation task in an experiment with the NT–33A documented in AFFDL–TR–74–9. Standard probe–and–drogue refueling procedures were used. However, adequate and desired performance objectives were not explicitly defined for this project. The performance objectives suggested in Verification Guidance are taken from a USAFTPS study of response–types for probe–and–drogue refueling performed with the NT–33A in October 1993.

A position–keeping evaluation task has been used extensively for tanker evaluations including the S–3 with a buddy store, the KC–10, the KC–130, and the KC–135. A detailed description of this test technique and lessons learned from these test programs is provided in AGARD CP–519.

Offset Precision Landing

This is another task which is so widely used for handling qualities evaluations that descriptions of it can be found in many handling qualities reports, particularly those that deal with approach and landing. The suggested performance objectives for the approach and touchdown phases are taken largely from Calspan experience with the NT–33A and the Total In–Flight Simulator (TIFS). Discussions of the use of this task can be found in NASA CR 172491, NASA CR 178188, AFWAL–TR–81–3118, and AIAA 93–3816.

Some data on the size of the suggested landing zone was provided in a USAFTPS project which studied the effect of different performance objectives on touchdown C–H ratings with three different Class IV aircraft: the F–15D, the F–16D, and the F/A–18B. The experiment looked at three different desired landing zones: 25 feet wide by 200 feet long, 50 feet wide by 400 feet long, and 75 feet wide by 600 feet long. C–H ratings for each aircraft and each landing zone were compared with the pilots' qualitative appraisal of each aircraft. For the 75x600 foot zone, all three aircraft received basically Level 1 C–H ratings. For the 50x400 foot zone, the F/A–18 received basically Level 1 C–H ratings, the F–15 had borderline Level 1/Level 2 C–H ratings, and the F–16 got basically Level 2 C–H ratings. For the 25x200 foot zone, all three aircraft received basically Level 2 C–H ratings. The project report found the results from the 50x400 foot zone to be most representative of the pilots' qualitative opinions of each aircraft.

Additional data on the size of the suggested landing zone was provided in a project by the 4950th Test Wing which studied the effect of different performance objectives on touchdown C–H ratings with three different Class III aircraft: the C–141A, the C–135A/E, and the C–18B. The experiment looked at four different desired landing zones: 20 feet wide by 200 feet long, 40 feet wide by 400 feet long, 60 feet wide by 800 feet long, and 80 feet wide by 1000 feet long. C–H ratings for each aircraft and each landing zone were compared with the pilots' qualitative appraisal of each aircraft. All three aircraft were considered Level 2 for the landing task. The final report (4950–FTR–93–05) recommended the 40x400 foot zone. For this zone, desired performance was met 6 out of 12 times, and the pilot ratings comprised two C–H ratings of 3 and four C–H ratings of 4. Interestingly, this suggested landing zone is very similar to the one recommended by USAFTPS for Class IV aircraft.

The performance objectives for STOL aircraft are taken from experience on the F–15 S/MTD program. Discussions of the tasks used in the S/MTD program can be found in AFWAL–TM–87–180–FIGC, WRDC–TR–89–3036, AFFTC–TR–91–29, and WL–TR–92–3027.

Takeoff

The takeoff task described in Verification Guidance was taken from the F–15 S/MTD program. This task was only used as an evaluation task on the McDonnell–Douglas and Wright Laboratory simulators. It was not used as an evaluation task in the flight test program. Descriptions and results of the use of this task can be found in AFWAL–TM–87–180–FIGC and in WRDC–TR–89–3036.

4.1.7 Aircraft Failure States. The contractor shall define and tabulate all Aircraft Failure States which can affect flying qualities. Aircraft Failure States consist of Aircraft Normal States modified by one or more malfunctions in aircraft components or systems; for example, a discrepancy between a selected configuration and an actual configuration. Those malfunctions that result in center–of–gravity positions outside the center–of–gravity envelope defined in 4.1.1 shall be included. Each mode of failure shall be considered in all subsequent Flight Phases.

REQUIREMENT RATIONALE (4.1.7)

This tabulation is the starting point for a failure modes and effects analysis, which is necessary in a complex aircraft to assure flying qualities adequate for mission effectiveness and flight safety.

REQUIREMENT GUIDANCE

The related MIL–F–8785C paragraph is 3.1.6.2.

Because of the exhaustive work often involved and low confidence in the failure probability calculations, there is a tendency for the procuring activity to substitute a priori list of specific failures. If a design is far enough along and not excessively complex, such an approach can work. See the guidance for 4.1.7.1. However, generally comprehensive reliability analyses will be required anyway.

Whether the approach to failure effects on flying qualities is probabilistic, generic or a combination, failure possibilities of the specific aircraft must be catalogued thoroughly enough to assure adequate mission effectiveness and flight safety.

REQUIREMENT LESSONS LEARNED

There is more to determining Failure States than just considering each component failure in turn. Two other types of effects must be considered. First, failure of one component in a certain mode may itself induce other failures in the system, so failure propagation must be investigated. Second, one event may cause loss of more than one part of the system or can affect all channels: a broken bracket, a single crack, a fire, an electrical short, inadequate ground checkout, etc.. The insidious nature of possible troubles emphasizes the need for caution in design applications.

5.1.7 Aircraft Failure States—verification. The contractor shall furnish the required data in accordance with the Contract Data Requirements List.

VERIFICATION RATIONALE (5.1.7)

Definition of aircraft failure states is basic to the application of the flying qualities requirements.

VERIFICATION GUIDANCE

Generally, compliance will amount to identifying pertinent items from the list required by the reliability specification, and checking for completeness. Although the task may seem formidable, the alternative to a thorough review is a certainty that something important will be overlooked.

VERIFICATION LESSONS LEARNED

TABLE X. Control–margin increments.

Flying Quality	$.\Delta_{FQ}/.\ n_c = 57.3\ CAP'/M_\Delta$ deg/g (for $T_{eff} \le 0.05$)
Stabilization	$.\Delta_{stab}/.\ n_c = 57.3\ \frac{g}{U_o} \cdot \frac{1/T_{sp_1} \cdot 1/T_{sp_2}}{M_\Delta \cdot 1/T_{\beta_2}}$ deg/g (linear, 2 DOF)
Turbulence	$\Delta / \ _w$ fn of M_w, M_Δ sp_c, sp_c, structural modes
	– most severe at low $\bar{q}$
	– 3 $_\Delta$ and $_w$ for severe turbulence recommended
Sensor Noise	$\Delta / \ _s$ fn of K_s, K_F, $_s$, $1/T_a$, sp_c, sp_c, $^2_{sp_o}$
Flying Quality	$\dot{\Delta}_{FQ}/n_c = 57.3\ CAP/(M_\Delta \cdot T_{eff})$ for desired CAP
Stabilization	$\dot{\Delta}_{stab}/n_c < \dot{\Delta}_{FQ}/n_c$ if FCS stability margins OK & $\frac{1}{T_{eff}} > \ _c$
	$\dot{\Delta}_{stab}/n_c$ fn of $1/T_{eff}$, $1/T_{sp_2}$, sp_c, sp_c
Turbulence	$\dot{\Delta}/ \ _w$ fn of $1/T_a$, sp_c, sp_c, M_Δ
	– most severe at low $\bar{q}$
	– 3 $\dot{_\Delta}$ recommended for control margin
Sensor Noise	$\dot{\Delta}/ \ _s = K_s K_F \cdot$ fn ($_s$, $1/T_a$ and, for low sp_c : $^2_{sp_o}$, sp_c, " sp_c
	– These parameters are not all independent
	– 3 $\dot{_\Delta}$ recommended for control margin

$.\ n_c$ is the commanded increment of normal acceleration
$1/T_n$ is the unstable pole of the transfer function (negative; 1/sec)
$^2_{sp_o}$ is the 2–deg–of–freedom product of the poles, 1/sec^2
sp_c and sp_c are the closed–loop frequency and damping ratio of the short period mode
CAP is ^{c} /. n , , CAP′ is ^c_o /. n ,
$_s$ is the sensor bandwidth
K_s, K_F are the sensor and forward–loop gains
$_s$, $_w$ are the rms intensities of sensor noise and vertical gusts
$_c$ is the crossover frequency of the $^c_\Delta/n_c$ transfer function
T_{eff} is the effective time constant of command–path plus forward–path control–loop elements (such as prefilters and actuators)
T_a is the time constant of the actuator ram

Supersedes page 149 of MIL–STD–1797A

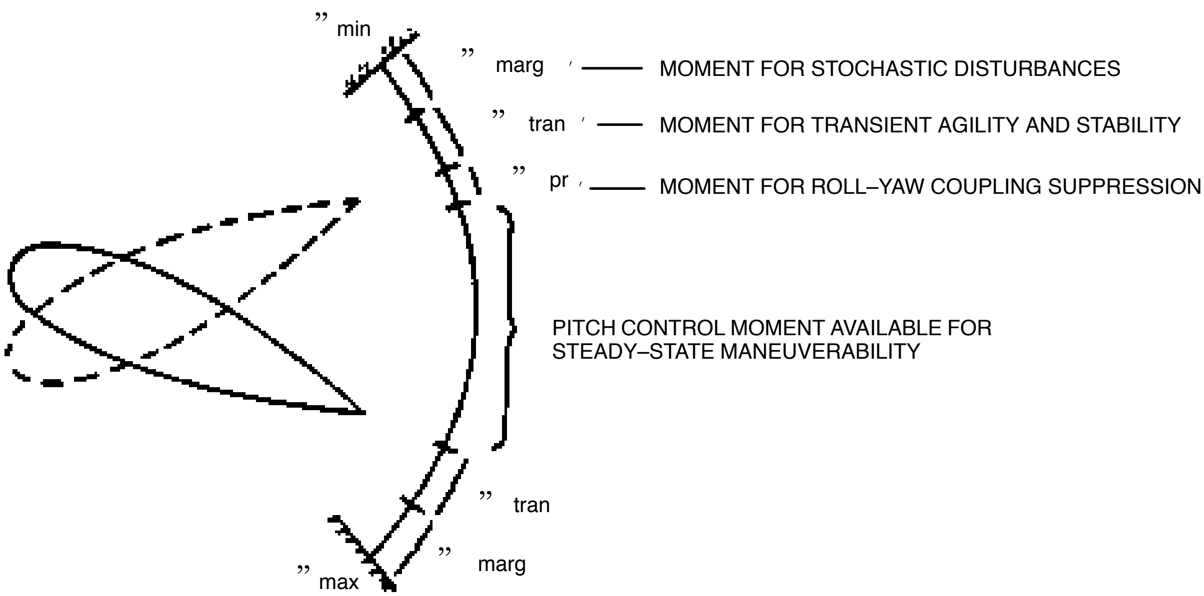


FIGURE 11. Control margin requirements.

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4.1.11.6 Pilot–in–the–loop oscillations (PIO). There shall be no tendency for pilot–in–the–loop oscillations, that is, sustained or uncontrollable oscillations resulting from efforts of the pilot to control the aircraft. More specific requirements are in 4.2.1.2, 4.2.2, 4.5.2, and 4.6.3.

REQUIREMENT RATIONALE (4.1.11.6)

This general qualitative requirement, applicable to all axes, covers those axes of control for which there is no data base for more specific requirements.

REQUIREMENT GUIDANCE

The applicable MIL–F–8785C requirements are paragraphs 3.2.2.3 and 3.3.3.

PIOs were a consideration in setting the boundaries of 4.2.1.2 and 4.5.1.3 through 4.5.1.5.

REQUIREMENT LESSONS LEARNED

Likely causes are equivalent time delay, control system friction, inappropriately–located zeros of aircraft transfer functions, or nonlinearities such as rate limiting, hysteresis, and abrupt control system gain changes. See the discussion under 4.2.2. NORAIR Rpt No. NOR–64–143 discusses a number of possible PIO mechanisms.

5.1.11.6 Pilot–in–the–loop oscillations (PIO) – verification. Verification shall be by analysis, simulation, and flight test. Final verification shall be by demonstration in the following tasks: _______________.

VERIFICATION RATIONALE

The need to use high–gain, closed–loop tasks to evaluate handling qualities, in addition to comparison with open–loop requirements, is fully discussed in the Verification Rationale of 5.1.6.1 through 5.1.6.3. An additional reason, if any more are needed, is that most of the open–loop requirements assume a linear system. Pilot evaluation in high–gain, closed–loop tasks is at this time the best evaluation of the effects of nonlinearities. This is particularly important in the evaluation of PIO tendencies because nonlinearities, such as rate limiting, hysteresis, abrupt gain changes, and aerodynamic nonlinearities, are some of the common causes of PIO.

VERIFICATION GUIDANCE

Pilot–vehicle analysis in the manner described in the discussion of the cited paragraphs should help in the design stage. Ground–based simulation may or may not show up any PIO tendencies. Flight evaluation in variable–stability aircraft is a valuable tool. Final determination will come from flight test of the actual vehicle.

The recommended tasks to demonstrate compliance with this requirement are the tasks described in Verification Guidance of 5.1.6.1 through 5.1.6.3 using the HQDT technique. AFFTC makes a distinction between HQDT and “operational” closed–loop evaluation tasks. The key element of the HQDT technique is that the pilot must attempt to totally eliminate any error in the performance of the task; he adopts the most aggressive control strategy that he can. Adequate and desired performance are not defined and Cooper–Harper ratings are not recommended. The reason for this is that, in the “operational” tasks, definition of adequate and desired performance encourages the pilot to adopt a control strategy which best meets these performance objectives. In the case of a PIO–prone airplane, attempting to totally eliminate any deviation may induce oscillations which reduce his performance, but by accepting small errors (reducing his gain) the pilot may be able to avoid these oscillations and still meet the performance objectives (which, by their definition, allow such a tactic). The HQDT technique does not allow the pilot to do this, thus exposing any possible handling qualities deficiencies. HQDT could be considered a “stress test” of handling qualities. For this reason, the HQDT technique is considered the best test of PIO tendencies.

HQDT is not exclusively a PIO evaluation technique. It is a general handling qualities evaluation technique. It is discussed in more detail here in the PIO requirement because it is a better PIO evaluation technique than the “operational” technique. On the other hand, the “operational” technique uses performance objectives more representative of operational use, and the C–H ratings provide a quantitative measure of flying qualities which can be related to the required Levels. Therefore, use of both techniques is recommended in the flight test evaluation, as well as parameter identification techniques and capture tasks. As mentioned in the Verification Rationale of 5.1.6.1 through 5.1.6.3, the recommended parts of the handling qualities evaluation are: 1) steps, doublets, and frequency sweeps for parameter identification and comparison to open–loop requirements, 2) capture tasks for pilot familiarization with aircraft dynamic response and evaluation of gross acquisition, 3) HQDT for initial handling qualities and PIO evaluation (HQDT may also provide good inputs for frequency–domain analysis), and 4) "operational" tasks for handling qualities evaluation with C–H ratings.

The PIO tendency classification scale shown on figure 12 has been developed specifically for evaluation of PIO tendencies. It can be used with either the HQDT or the "operational" techniques. Comparing the PIO rating descriptions with descriptions of Levels of flying qualities, a rough approximation would be: PIO ratings of 1 or 2 would be Level 1, PIO ratings of 3 or 4 would be Level 2, and a PIO rating of 5 would be Level 3. A PIO rating of 6 would be extremely dangerous.

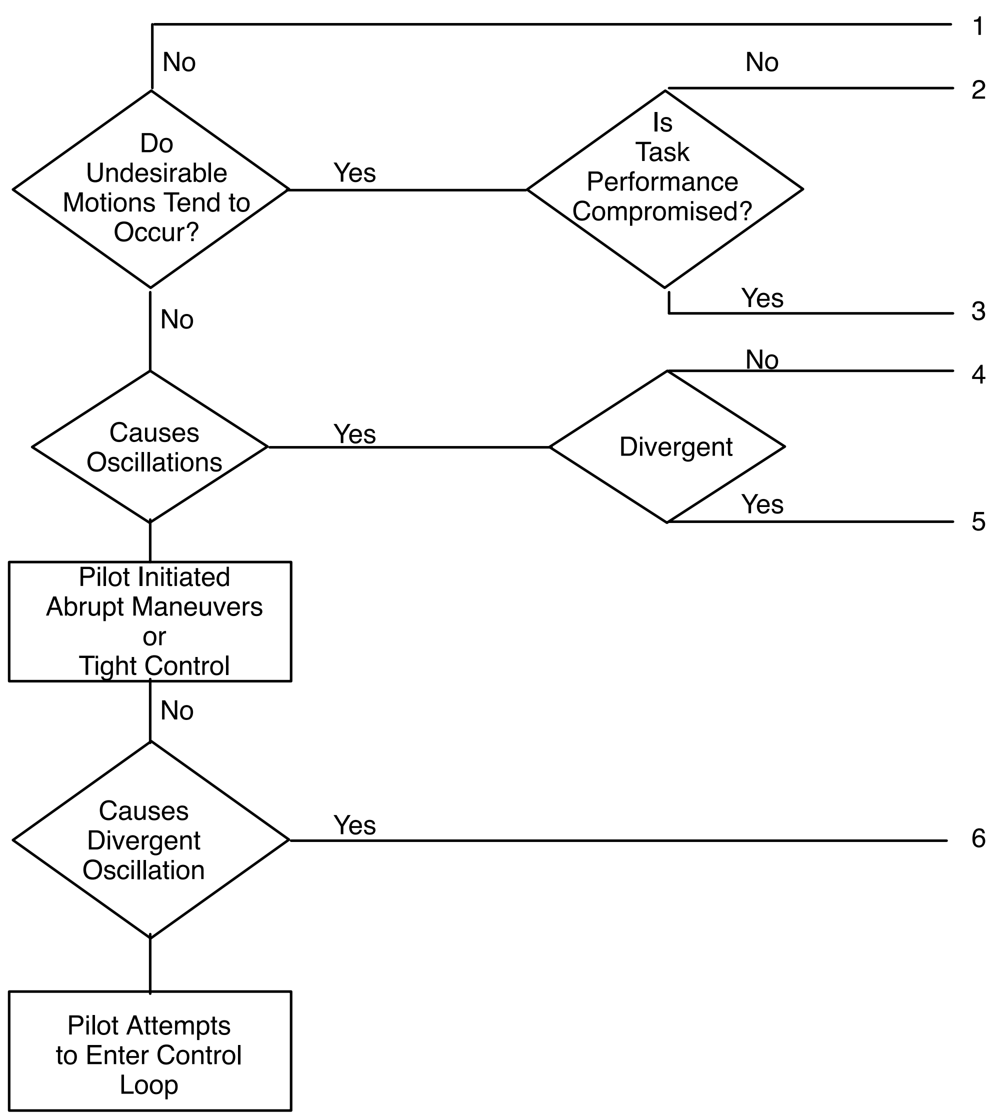

FIGURE 12. PIO tendency classification from AFWAL–TR–81–3118.

Tom Twisdale provides some guidance on possible HQDT tasks:

> Probably any test maneuver that allows the evaluation pilot to aggressively and assiduously track a precision aim point is a suitable HQDT test maneuver. In HQDT testing, the test maneuver is not nearly as important as the piloting technique. It is the piloting technique that increases the evaluation pilot's bandwidth and makes possible a good handling qualities evaluation. For this reason there is no exclusive catalog of HQDT maneuvers. The ones discussed below have worked well, but others, perhaps better suited to a particular airplane, may be invented as the need arises.
>
> Air–to–Air HQDT
>
> Air–to–air HQDT involves tracking a precision aimpoint on a target airplane while using a fixed, or non–computing gunsight. There are three main variations of air–to–air HQDT: constant load factor HQDT at a constant range of about 1500 feet; wind–up turn HQDT at a constant range of about 1500 feet; and HQDT while closing on the target.
>
> The purpose of a constant load factor air–to–air HQDT maneuver is to evaluate handling qualities at a specific angle of attack. The maneuver begins with the test airplane positioned 1500 feet behind and offset above, or below, or to the inside of the target. The offset position is helpful in avoiding jetwake encounters. At the evaluation pilot's signal the target pilot rolls smoothly into a turn and slowly increases load factor until the test load factor is attained. A g onset rate of two seconds or so per g is satisfactory. When the test load factor has been attained the target pilot calls "on condition" and maintains the turn and the test conditions for the specified period of time, which will depend on the test and analysis objectives. During the load factor build–up the evaluation pilot turns on the airborne instrumentation system and positions the target airplane 50 mils or so from the pipper or aiming index at a clock position of 1:30, 4:30, 7:30, or 10:30. After the target pilot calls "on condition" the evaluation pilot calls "tracking" and drives the pipper toward the precision aim point to initiate the evaluation. The evaluation pilot continues to track while using the HQDT piloting technique, until the target pilot or other aircrew or the control room calls "time". However the maneuver is not concluded until the evaluation pilot calls "end tracking". At that time the target pilot rolls out of the turn.
>
> The constant load factor air–to–air HQDT maneuver may be a constant turn to the left or right, or turn reversals may be included. When reversals are included they should be performed at constant load factor. The evaluation pilot continues to track the precision aim point throughout the reversal, always using the HQDT piloting technique.
>
> The evaluation pilot should maintain a 1500–foot separation from the target airplane. Variations of a few hundred feet either way are permissible, but range to the target should not be allowed to exceed 2000 feet. Range may be determined stadiometrically with adequate accuracy.
>
> The purpose of a wind–up turn air–to–air HQDT maneuver is to quickly explore handling qualities across a range of angle of attack. The maneuver gets under way when the target pilot establishes the test conditions and calls "on condition". The evaluation pilot positions the test airplane 1500 feet behind and offset above, or below, or to the inside of the target. The offset position is helpful in avoiding jetwake encounters. The evaluation pilot turns on the airborne instrumentation system and positions the target airplane 50 mils or so from the pipper or aiming index at a clock position of 1:30, 4:30, 7:30, or 10:30. The evaluation pilot then signals the target pilot to begin the maneuver. The target pilot rolls smoothly into a turn and slowly increases load factor at a g onset rate of five or six seconds per g. As the target airplane begins rolling into the wind–up turn, the evaluation pilot calls "tracking" and drives the pipper toward the precision aim point to initiate the evaluation. The evaluation pilot continues to track while using the HQDT technique, until the target pilot attains the target load factor and calls "target g". The target load factor is maintained until the evaluation pilot calls "end tracking". At that time the target pilot may unload and roll out of the turn.

The evaluation pilot should maintain a 1500–foot separation from the target airplane. Variations of a few hundred feet either way are permissible, but range to the target should not be allowed to exceed 2000 feet. Range may be determined stadiometrically with adequate accuracy.

In HQDT with closure, the evaluation pilot slowly closes on the target airplane while tracking. The purpose of the closing HQDT maneuver is to help the evaluation pilot distinguish attitude dynamics from normal and lateral acceleration dynamics. Attitude dynamics are evident at any tracking range, but translation caused by normal and lateral acceleration become more noticeable as the evaluation pilot closes on the target.

In a closing HQDT maneuver the target airplane may either fly straight and level, maneuver gently in pitch and roll, or perform a constant load factor turn. Gently maneuvering or a constant load factor turn is often preferred because it helps to increase the evaluation pilot's bandwidth. In –all other respects the closing maneuver is similar to a constant load factor or wind–up tracking turn.

The closing HQDT maneuver can begin once the target pilot has established the test conditions and calls "on condition". The evaluation pilot positions the test airplane 1500 feet behind and above, below, or to the inside of the target; turns on the airborne instrumentation system; and positions the target airplane 50 mils or so from the pipper or aiming index at a clock position of 1:30, 4:30, 7:30, or 10:30. The evaluation pilot then signals the target pilot to begin the maneuver. The target pilot flies straight and level; or begins to maneuver gently and randomly in pitch and roll; or performs a constant load factor turn. The evaluation pilot calls "tracking" and drives the pipper toward the precision aim point to initiate the evaluation. The evaluation pilot continues to track, using the HQDT technique, while slowly closing on the target airplane. The rate of closure will depend on the desired tracking time (which will depend on the test and analysis objectives). The evaluation pilot may find it easier to control the rate of closure if the control room or the target pilot or other aircrew announce the elapsed time in five second increments. At the end of the specified tracking time, the target pilot or other aircrew or the control room calls "time". However the maneuver is not concluded until the evaluation pilot calls "end tracking".

Power Approach HQDT

Power approach HQDT is air–to–air HQDT performed with the test airplane configured for power approach. This maneuver is designed to evaluate approach and landing handling qualities at a safe altitude (10,000 to 15,000 feet), rather than a few feet above the ground during a real landing. Power approach HQDT may be flown with or without closure, however closure is a desirable feature because it helps the evaluation pilot distinguish between attitude and translation dynamics.

The target airplane may either fly straight and level or maneuver gently in pitch and roll. Maneuvering gently is often preferred because it helps to increase the evaluation pilot's bandwidth. In all other respects the power approach HQDT maneuver is similar to a closing HQDT maneuver.

Closure during the maneuver is useful for distinguishing attitude dynamics from normal and lateral acceleration dynamics. Attitude dynamics are evident at any tracking range, but translation caused by normal and lateral acceleration become more noticeable as the evaluation pilot closes on the target.

Jet–wake encounters are a frequent source of difficulty during power approach HQDT testing. Simple geometry, together with a maneuvering target airplane, make jet–wake encounters difficult to avoid. The slow speeds introduce the risk that a jet–wake encounter will precipitate a stall or departure, although this has never occurred. There are two solutions to the problem of jet–wake encounters. One is to use a small propellor–driven airplane as a target. Excellent candidates are the T–34C or Beechcraft Bonanza, or similar airplanes.

These airplanes can easily match the slowest speeds of most military airplanes, and they produce very little propwash. The second solution is to use a target that is programmed into a flight test head–up display, similar to the head–up display used on the Calspan NT–33.

Air–to–Ground HQDT

Air–to–ground HQDT involves tracking a precision aimpoint on the ground with a fixed, or non–computing gunsight. Shallow or steep dive angles may be used. Shallow dive angles approximate strafing attack profiles and steeper angles approximate ballistic weapons delivery profiles.

The evaluation pilot trims the airplane at the specified dive entry altitude and airspeed, turns on the airborne instrumentation system, calls "on condition", and rolls or pitches to the specified dive angle. When the outer ring of the gunsight reticle crosses the precision aim point, the evaluation pilot calls "tracking" and commences to track the precision aim point using the HQDT piloting technique. The evaluation pilot continues to track until the recovery altitude is reached, then calls "end tracking" and recovers from the dive.

A useful variation on the basic maneuver is to track two or more precision aim points, instead of one. For example, precision aim points may be positioned at each apex of an imaginary isosceles triangle laid out on the ground. This triangle has a base of 100 feet and a height of 375 feet (for 15 degree dive angles) or a height of 100 feet (for 45 degree dive angles) . During the maneuver the evaluation pilot randomly switches from one precision aim point to another, perhaps at a signal from the control room.

Boom Tracking HQDT

In boom tracking, the evaluation pilot tracks the nozzle on an aerial refueling boom. This maneuver is designed to explore aerial refueling handling qualities without the risk of close proximity to a tanker and a refueling boom.

The tanker airplane establishes the test conditions of Mach number (or airspeed) and altitude and maintains them during the test maneuver. The boom operator positions the refueling boom at zero degrees of azimuth and a midrange elevation angle. When the test conditions have been established the tanker pilot or the boom operator call "on condition". The evaluation pilot moves the test airplane into position a short distance behind the nozzle (20 to 50 feet) and positions the nozzle about 50 mils from the pipper or aiming index at a clock position of 1:30, 4:30, 7:30, or 10:30. To begin the maneuver, the evaluation pilot turns on the airborne instrumentation system, calls "tracking", and drives the pipper toward the nozzle. The evaluation pilot continues to track the nozzle, using the HQDT piloting technique, while the boom operator randomly maneuvers the refueling boom in azimuth and elevation. The boom motion should be a combination of gentle and abrupt changes in rate and position. After the specified period of tracking time (which will depend on the test and analysis objectives) has elapsed, the control room or another crew member calls "time". The maneuver is not concluded, however, until the evaluation pilot calls "end tracking".

Formation HQDT

In formation HQDT, the evaluation pilot attempts to maintain a precisely defined position relative to the lead airplane during a series of gentle maneuvers. Properly done, formation HQDT can highlight for the evaluation pilot the vertical and lateral translation dynamics of the test airplane. This maneuver is also useful for evaluating the throttle response of the airplane. Care must be taken not to force the evaluation pilot to fly too close to the lead airplane. Close proximity can increase bandwidth, but too close proximity can reduce it. As the separation between airplanes narrows, good and prudent pilots will reduce their bandwidth to reduce the risk of collision.

NEW PAGE

VERIFICATION LESSONS LEARNED

Attention to flying qualities per se during flight control design will take care of many potential problems. PIOs may occur early in the aircraft life as on the YF–16 high speed taxi test that got airborne before its first flight, or later in service, as with the T–38 as more pilots got to fly it. If PIO is not found readily, it should be sought during the flight test program.

4.2.2 Pilot–in–the–loop pitch oscillations. There shall be no tendency for sustained or uncontrollable pitch oscillations resulting from efforts of the pilot to control the aircraft. The phase angle of the pitch attitude frequency response to pitch stick force at the criterion frequency, $_c$, shall be greater than or equal to ____. If this phase angle is less than ____, the phase parameter of normal acceleration at the pilot's station, β, at the same criterion frequency, shall be greater than or equal to ______. Furthermore, the requirements of 4.2.1.2, 4.2.8.1, 4.2.8.2, and 4.2.8.4 must be met.

REQUIREMENT RATIONALE (4.2.2)

The purpose of this requirement is to insure that abrupt maneuvers or aggressive tracking behavior will not result in instabilities of the closed–loop pilot/aircraft system. Any such tendency will degrade or even destroy mission effectiveness and likely will be dangerous.

REQUIREMENT GUIDANCE

The related MIL–F–8785C requirement is paragraph 3.2.2.3.

Recommended values:

The recommended minimum phase angle of the pitch attitude frequency response to the pitch stick force at the criterion frequency, $_c$, is –180 .

The value of $_c$ is determined as follows:

$$_c = (0.24 \text{ rad–oct/dB–sec})\ \overline{S} + 6.0 \text{ rad/sec}$$

where $\overline{S}$ is the average slope of $\left| \frac{(s)}{F_{es}(s)} \right|$ in dB/oct over the interval from 1 to 6 rad/sec.

If the phase angle of pitch attitude frequency response to pitch stick force is less than –160 , then the recommended minimum value of the phase parameter of normal acceleration at the pilot's station, β, at $_c$, is –180′

The phase parameter of normal acceleration at the pilot's station, β, is defined by:

$$\beta" \ _c \,.\, \Delta \,/\, \frac{a_{z_p}(j\ _c)}{F_{es}(j\ _c)} - (14.3 \text{ deg–sec/rad}) \ _c$$

where a_{z_p} is normal acceleration at the pilot's station.

A related requirement in 4.2.8.2. Also, see 4.1.11.6 for a general PIO requirement. The qualitative requirement of MIL–F–8785C is generalized in view of uncertainties in the state–of–the–art of flight control system design, a tacit recognition of the complexity of the PIO problem; no detailed specification is, at this time, a guarantee against building a PIO–prone airframe/flight–control–system combination.

The requirement precludes PIO, PIO tendencies or general handling qualities deficiencies resulting from inadequate pilot–vehicle closed–loop gain and phase margins. PIO has occurred in the T–38A, A4D, and YF–12 due to abrupt amplitude–dependent changes in aircraft dynamic response to pilot control inputs. These effects can be of mechanical origin, e.g. bobweights coupled with static friction, or due to saturation of elements within the control system, or due to compensation added to the automatic control system. Other known sources are short–period dynamics (e.g. large $_{sp}\,T\ _2$), feel system phasing (e.g. effective bobweight location not far enough forward), and sensitive control force and motion gradients. AFFDL–TR–69–72 and Norair Rpt NOR–64–143 can furnish some insight.

The requirement above is popularly known as the Smith–Geddes PIO criteria. It was proposed in its original form in AFFDL–TR–77–57. It was more fully developed as a general longitudinal response requirement in AFFDL–TR–78–154, and further developed and extended to the lateral–directional axis in

AFWAL–TR–81–3090. No specific method for determining $\bar{S}$ was required in AFFDL–TR–78–154. Smith originally recommended a range of 2 to 6 rad/sec and computed $\bar{S}$ as the average of three linear approximations of slopes between pairs of points one octave apart, i.e.:

$$\bar{S} = \frac{1}{3}\left[\left|\frac{}{F_{es}}(4j)\right| - \left|\frac{}{F_{es}}(2j)\right| + \left|\frac{}{F_{es}}(5j)\right| - \left|\frac{}{F_{es}}(2.5j)\right| + \left|\frac{}{F_{es}}(6j)\right| - \left|\frac{}{F_{es}}(3j)\right| \right]$$

In AFWAL–TR–81–3090 the frequency range was extended to 1 to 6 rad/sec, and a similar formula was used to compute $\bar{S}$ using five slopes instead of three, i.e.:

$$\bar{S} = \frac{1}{5}\left[\left|\frac{}{F_{es}}(2j)\right| - \left|\frac{}{F_{es}}(1j)\right| + \left|\frac{}{F_{es}}(3j)\right| - \left|\frac{}{F_{es}}(1.5j)\right| + \left|\frac{}{F_{es}}(4j)\right| - \left|\frac{}{F_{es}}(2j)\right| + \left|\frac{}{F_{es}}(5j)\right| - \left|\frac{}{F_{es}}(2.5j)\right| + \left|\frac{}{F_{es}}(6j)\right| - \left|\frac{}{F_{es}}(3j)\right| \right]$$

This modification brought predictions of $_c$ more in line with observations based on Landing Approach Higher Order System (LAHOS) data. AFFDL–TR–78–154 advises using a consistent method to calculate $\bar{S}$, even when the slope of

$\left|\frac{(s)}{F_{es}(s)}\right|$ varies considerably in the 1 to 6 rad/sec range.

The criterion frequency, $_c$, is an approximation of the crossover frequency of the pilot–vehicle system during pitch attitude tracking. This approximation is based on data from AFFDL–TR–65–15 shown on figure 276. This figure shows crossover frequency as a function of forcing function bandwidth for different controlled elements. The equation for $_c$ was derived from this data as shown on figure 277, taken from AFFDL–TR–78–154. This equation was altered slightly in AFWAL–TR–81–3090 to the form recommended in Requirement Guidance. This modification was made in conjunction with the modifications in the calculation of $\bar{S}$ to better fit the LAHOS data and F–15 CAS–off, supersonic PIO experiences.

The third parameter in this requirement, $(\ _c)$, is a phase parameter associated with the normal acceleration sensed at the pilot's station. It consists of the aircraft phase angle of normal acceleration frequency response plus a phase angle due to an assumed pilot response delay at the pitch attitude criterion frequency, $_c$. This parameter becomes important if there is too much phase lag in the pitch attitude response to stick force; thus the condition that this parameter be considered when the phase angle of the pitch attitude response to stick force is less than –160 . This is a fundamental element of the Smith–Geddes criteria, originally derived in AFFDL–TR–77–57, and was included in its original form in MIL–F–8785C and MIL–STD–1797. In the original form, was evaluated at $_R$, where $_R$ was defined as any frequency within the range of 1 to 10 rad/sec at which lightly damped (resonant) oscillations in pitch attitude could result from turbulence inputs or from piloted control of the aircraft when used in the intended manner. In AFFDL–TR–78–154, $_R$ was replaced by $_c$ as defined above. The concept behind this part of the requirement is that, if the pitch attitude ( ) loop is resonant at $_c$, then the pilot may attempt to control normal acceleration, a z_p, instead of . The aircraft will be PIO prone if there is too much phase lag in this response. The criteria for this requirement are based largely on correlation with the Neal–Smith data base (AFFDL–TR–70–74).

The statement that requirements 4.2.1.2, 4.2.2, 4.2.8.1, 4.2.8.2, and 4.2.8.4 must also be met would seem to be redundant, since these are already requirements. However, recent history would seem to indicate that, because the term PIO does not appear in these requirements, the importance of these requirements in precluding PIO is not appreciated. Many recent PIO incidents can be traced directly to problems addressed by these requirements. Therefore, these requirements are repeated here in the PIO requirement to insure that their significance in precluding PIO tendencies is understood.

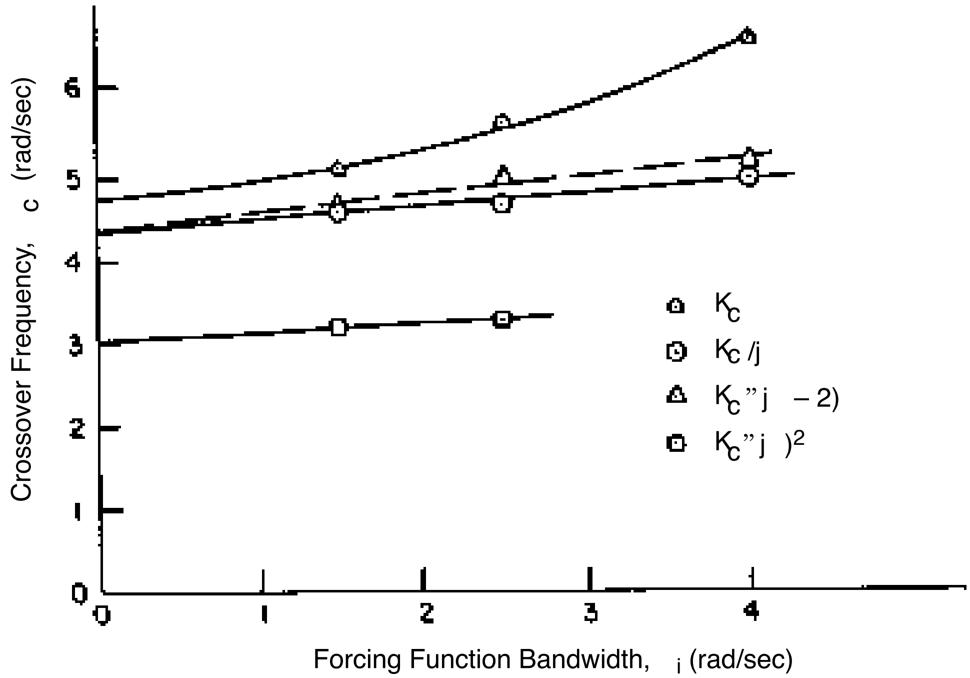

FIGURE 276. Variation of Crossover Frequency with Pitch Attitude Dynamics (from AFFDL–TR–65–15).

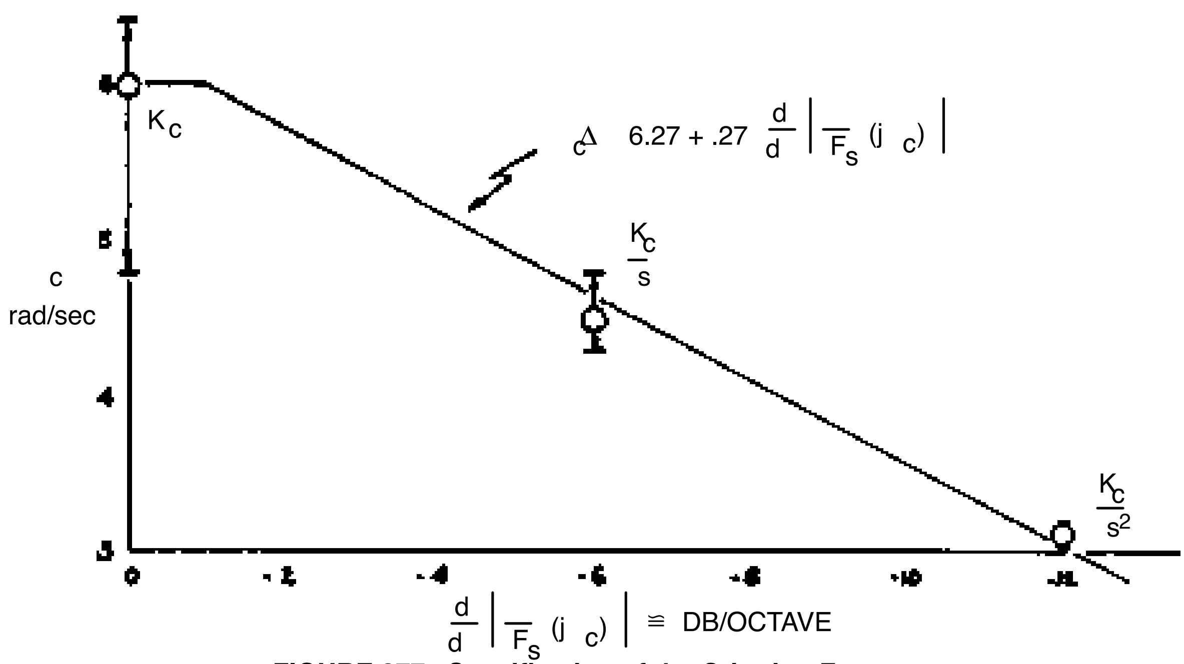

FIGURE 277. Specification of the Criterion Frequency.

Gibson's views of PIOs are taken directly from ICAS–86–5.3.4:

High order characteristics are associated with pilot–vehicle closed–loop handling problems or PIO. As this term has been used to describe low order problems, the differences should be clearly understood. The abrupt pitch bobble type is discontinuous, consisting of repeated tracking corrections. The sluggish pitch overdriving type is also discontinuous with input pulses to stop the unpredictable excess in response. Although the aircraft is not under complete control, it is not out of control.

High order PIO is a continuous out of control attitude instability, the amplitude ranging from small to large and potentially destructive. Because the problem is due to inadequate pilot–vehicle closed loop gain and phase margins, examination of the pitch attitude frequency response identifies the cause and the solution.

Figure [76] shows the features which separate low and high–order pitch handling. The area of interest can be confined to the region of phase lags between 180 and 200 degrees which determines the PIO frequency. This arises from the success of the synchronous pilot (NOR–64–143) in PIO analysis, assuming that any pre–PIO equalization is abandoned for a pure gain behaviour in the undamped or divergent oscillation. The correct frequency is adopted instantaneously with the stick in phase with the pitch attitude error and 180 degrees out of phase with the attitude. The stick is not always moved so purely in practice, but very often the pilot can be seen to apply the stick a little too quickly and then hold it while waiting for the pitch rate reversal before also reversing the stick.

The tendency of a configuration to PIO can therefore be assessed without using a pilot model by empirically establishing the range of characteristics found in actual PIO examples. Enough have now been published to do this with considerable accuracy. An important feature at the PIO frequency is the response gain. If this is small enough, dangerous oscillation amplitudes cannot occur, and PIO has not been found where this is less than 0. 1 degrees per pound of stick force. This is not a completely necessary condition but it is a highly desirable design aim.

PIO's have occurred most frequently, though not exclusively, in the landing flare. The connection with the commonplace stick pumping is well established. This subconscious excitation of pitch acceleration in the flare occurs near the same frequency as a PIO. If the attitude in the oscillation suddenly intrudes into the pilot's awareness, a ready–made PIO is already in existence. The lower the frequency, the larger is the attitude oscillation at the usual acceleration amplitude of about 6 deg/sec^2, and the more likely the conversion becomes. This indicates strongly the desirability of a high crossover frequency through the PIO region.

While an oscillation amplitude of less than 0.5–degrees in the flare will not usually be noticed, the one significantly more than a degree is very likely to, this or the corresponding pumping/PIO frequency is not an ideal parameter for correlation. The most successful has proved to be the rate at which the pitch attitude phase lag increases with frequency in the PIO lag crossover region, equally applicable to the landing or to target tracking tasks. By the nature of the attitude frequency response, if the crossover frequency is low and the attitude attenuates only slowly towards the crossover region, the phase rate is large. If the frequency is high and there is substantial attenuation, the phase rate is low. The gain margin is increased, the stick pumping amplitude is reduced, and the tendency to PIO is decreased automatically by designing a low phase rate into the control laws.

This simple attitude parameter alone is almost sufficient to quantify the tendency to high order PIO, and it correlates well with available examples of high order PIO. Figure [77] shows the trends, with an accuracy good enough to allow Level 1, 2, and 3 boundaries to be drawn, if desired. For the control law designer it is enough to aim for a phase rate of less than 100 degrees per cps and attitude response phase rate of less than 100 degrees per cps and attitude response smaller than 0.1 deg/lb at the crossover. These characteristics are a natural feature of low order aircraft whose attitude phase lag exceeds 180 degrees due to the power control and so could in principle suffer from PIO, yet do not. Early examples of bobweight PIO were high–order in kind and are found to have had very large phase rates with the stick free.

For most combat aircraft configurations, consideration of normal acceleration effects does not improve the PIO analysis. The g at the cockpit is usually attenuated and phase advanced relative to the cg and will often not reach the 180 degrees lag necessary for piloted instability. Human sensing of the g response is poor and at the initiation of the PIO the g may be undetectable. In large aircraft with the cockpit far ahead of the cg, the heave can have a significant effect and has to be taken into account in the dominant requirement to optimize the pitch attitude behaviour.

Although the attitude to stick force response gain is significant in PIO, there is little evidence that a damper modifies the pilot's stick phasing in a PIO and only the stiffness component should be used. Where PIO tendencies exist, they will be exacerbated by a high stick stiffness. Gradients of 5 to 8 lb/in with forces of 2 to 2.5 lb/g have proved to be extremely satisfactory for [fly–by–wire] aircraft. Designed to the phase rate and gain margin criteria discussed above, the attitude gain phase rate and gain at the PIO frequency is only some 0.5 deg/in. In AFFDL–TR–74–9, case 4D had high phase rate and low PIO gain margin. With a gradient of 22 lb/in and 6.7 lb/g it had an attitude gain of 7 deg/in at the PIO frequency. Not surprisingly it suffered from continuous pitch oscillations and severe tracking PIO, earning ratings of 9 and 10.

The boundaries in the frequency response criteria of figure [75] are based directly on these considerations and will eliminate high order PIO. Low order PIO will also be eliminated by the optimization criteria given above.

REQUIREMENT LESSONS LEARNED

The Smith–Geddes criteria has been used by AFFTC with considerable success for several years. The criteria has been used to analyze PIOs in the Space Shuttle, the F–15 with CAS–off, the AFTI/F–16, the AFTI/F–111, the F–15 S/MTD, the YF–22, and the C–17. Application of the criteria to the Space Shuttle was documented in "Prediction and Occurence of Pilot–Induced Oscillations in a Flight Test Aircraft" by Twisdale and Kirsten. In an analysis of three PIOs in the Space Shuttle, the Smith–Geddes criteria correctly predicted the PIO tendency and closely predicted the frequency of the PIO. For a PIO in landing flare, the criteria predicted a frequency of 3.5 rad/sec and the frequency of the observed PIO was 3.6 rad/sec. In another PIO at an altitude of 18,000 ft and a speed of 610 ft/sec, the criteria predicted a frequency of 3.3 rad/sec and the observed frequency was 3.1 rad/sec. In the final example, at a similar flight condition, a PIO occurred while tracking a cockpit display. When the display dynamics were added to the analysis, the criteria accurately predicted the observed PIO frequency of 2.0 rad/sec.

A valuable lesson learned in the determination of the criterion frequency, $_c$, is found in a Northrop white paper, "Evaluation of B–2 Susceptibility to Pilot–Induced Oscillations" by Margo L. Givens and Frank L. George, presented at the Flying Qualities Working Group at the 1994 AIAA Atmospheric Flight Mechanics Conference.

For the most part, the approach taken was as recommended by Ralph Smith in [AFFDL–TR–78–154] which presented a straight forward process of evaluation. Exceptions were made for criterion frequency selection. The recommended method [in AFFDL–TR–78–154] for criterion frequency selection is based on calculating an average slope of the pitch attitude–to–controller Bode magnitude plot in the range of 2. 0 to 6. 0 rad/sec and then applying this value to the [$_c$] formula. This frequency range stipulation was often inappropriate for the B–2 which has higher break frequencies than those systems described in the [Smith–Geddes] documentation. Because the validity of a [Smith–Geddes] analysis is dependent on the correct selection of the criterion frequency, three other methods of criterion frequency selection were evaluated.

The first method, which has been used by Ralph Smith in the past, involved selecting parameters for a pilot model, closing the pitch attitude loop, and obtaining an n_z to $_{gust}$ response power spectral density (PSD) in search of resonant frequencies which would be defined as the criterion frequencies. The implementation of this method was unproductive because no resonant frequencies were found in the B–2 n_z PSDs.

The second method adapted the recommended $_c$ derivation formula to use the slope calculated after the short period break rather than the average slope in the 2.0 to 6.0 rad/sec frequency range. This method worked quite well for most of the cases. Because of the occasional case which produced questionable results, a third method of frequency determination was devised for use as a validity check on criterion frequencies derived using method 2.

The third approach used typical B–2 pilot pitch stick input frequencies as the criterion frequencies. These frequencies were determined by calculating PSDs from stick, n_z , and time histories of landings and refuelings extracted from flight test data. It was found that the $_c$ values calculated with the second method were consistent with these flight data pilot stick input frequency ranges.

A very good summary report on PIOs is given in NOR–64–143. The following paragraphs from that reference discuss the causes of PIOs:

There are several ways of looking at the causes of a PIO. One is to catalog all the PIO situations ever recorded, including all the necessary subsystem details, etc., and then to say that each combination of vehicle and subsystem when combined with the pilot was the cause of a PIO. Another way is to note that certain system phenomena such as stick–force–to–control–deflection hysteresis often lead to PIO when other conditions are right. A third way, and one which seems to transcend the difficulties of the previous two, is to say that certain inherent human physical limitations are the basic cause for any PIO. This is not to degrade the human pilot's role but, instead, to emphasize it, because it is unlikely that any black–box could be devised which is as clever and effective in coping with unmanageable controlled elements as a skilled pilot. Were it not for the pilot's versatile gain adaptability, many flight conditions would be unstable. But there is a limit to the rapidity with which the human can adapt, and this can sometimes lead to a PIO.

When referred to the pilot, then, the basic causes of PIO seem to fall into the following categories:

1. Incomplete pilot equalization

   a. Incomplete training

   b. Inappropriate transfer of adaptation (i.e., carry over of improper techniques from another aircraft)

2. Excessive–demands on pilot adaptation

   a. Required gain, lead, or lag lie outside the range of normal capabilities

   b. Rate of adaptation is too slow to preclude oscillation

   c. Inadequate capability to cope with system nonlinearities

3. Limb–manipulator coupling

   a. Impedance of neuromuscular system (including limb) on control stick or pedals changes feel system dynamics

b. Motion–induced limb force feedback (e.g., arm becomes a bobweight)

Table XIV, from NOR–64–143, lists some known PIO cases and their probable causes for then–current (early 1960s) aircraft. The causes are equally relevant for modern aircraft, and the lessons learned from the cases listed are valuable in preventing PIOs.

5.2.2 Pilot–in–the–loop oscillations – verification. Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (5.2.2)

It would be an easy matter for the engineers of the procuring agency to ascertain compliance with this paragraph without relying on pilot/vehicle analysis methods. For example, $_{c}$ and the specified phase lag can easily be obtained from simulator or in–flight time histories (ground–based simulations will not show up acceleration–dependent PIO tendencies). Nonetheless, analytical estimates can – and should – be made by the airframe manufacturer as part of the design evolution. For flight evaluation, the PIO tendency classification scale of figure 12 will be helpful.

VERIFICATION GUIDANCE

The user should refer to AFFDL–TR–77–57, AFFDL–TR–78–154, and AFWAL–TR–81–3090 when applying the quantitative requirement. PIOs are associated with abrupt maneuvers and precise tracking as in air–to–air gunnery, formation flying, flare, and touchdown. PIOs observed in flight are often not obtained in ground–based simulators, even ones with some motion. Tight, aggressive pilot control action will tend to bring on any PIO tendencies. High sensitivity to control inputs is often a factor. Some pilots are more PIO–prone than others, depending upon piloting technique.

VERIFICATION LESSONS LEARNED

These requirements are an attempt to catch and correct any PIO tendencies as early as possible in the design, when changes are easiest and least costly to make. They also have been found helpful in identifying PIO tendencies in flight and determining fixes.

TABLE XIV. Classification of some known PIO cases (from NOR–64–143).

Examples shown as: SPECIES (Aircraft): Critical Subsystem; Critical Flight Condition; Remarks

CLASS	TYPE		
	I. LINEAR	II. SERIES NONLINEAR ELEMENTS	III. SUBSIDIARY FEEDBACK NONLINEAR ELEMENTS
PITCH	IMPROPER SIMULATION; D, V: a: Abnormally high value of $1/T_{\theta 2}$ and low $\beta\Delta_{sp}$ led to zero β_{sp} when regulating large disturbances. GCA–INDUCED PHUGOID (C–97): D: c, b: Lag from radar–detected error to voice command led to unstable closed–loop phugoid mode. ARM ON STICK (A4D–1, T–38A): F: a: Arm mass increases feel system inertia, leads via B feedback to unstable coupling with short–period dynamics if pilot merely hangs loosely onto stick after a large input.	PORPOISING (SB2C–1): F: c: Hysteresis in stick versus elevator deflection resulted in low frequency speed and climb oscillations. J. C. MANEUVER (F–86D, F–100C): F, S: a: Valve friction plus compliant cabling resulted in large oscillations at short period. PITCH–UP (XF–104, F–101B, F–102A): V: c: Unstable kink in M( ) curve led to moderate–period oscillations of varying amplitudes (depending on extent and nature of the kink) during maneuvers near the critical angle of attack. LANDING PIO (X–15): S: b: Closed–loop around elevator rate–limiting caused moderate oscillations at short period.	BOBWEIGHT BREAKOUT (A4D–1, T–38A): F, B: a: At high–g maneuvers the bobweight overcomes system friction and reduces apparent damping of the aircraft in response to force inputs, resulting in large oscillations at short period. LOSS OF PITCH DAMPER
LATERAL–DIRECTIONAL	Δ_{ϕ}/Δ_d EFFECT (X–15, T–33VSA, F–101B, F–106A, KC–135A, B–58): V: c: Zeros of roll/aileron transfer function are higher than dutch roll frequency, $\lvert \Delta_{\phi}/\Delta_d \rvert > 1.0$, leading to closed–loop instability at low β_d conditions. BORESIGHT OSCILLATIONS (F–5A): D, V: c: Spiral roll mode driven unstable if roll information is degraded during gunnery.		LOSS OF YAW DAMPER
YAW	FUEL SLOSH SNAKING (KC–135A, T–37A): V: c: Fuel slosh mode couples with dutch roll mode when rudder used to stop yaw oscillations.	TRANSONIC SNEAKING (A3D): V, F: a, c: Separation over rudder causes control reversal for small deflections, leading to limit cycle if rudder used to damp yaw oscillations.	
ROLL	NONE KNOWN	PILOT–INDUCED CHATTER (F–104B): A: c: Small limit cycle due to damper aggravated whenever pilot attempted to control it.	

* Critical Subsystems:
D = Display
F = Feel system (except B)
B = Bobweight
S = Power servo actuator
V = Vehicle (airframe)
A = Augmentor (damper)

** Critical Flight Conditions:
a = Low altitude, near–sonic Mach
b = Landing approach and takeoff
c = Cruise

4.2.3 Residual pitch oscillations. In calm air, any sustained residual oscillations shall not interfere with the pilot's ability to perform the tasks required in service use of the aircraft. For Levels 1 and 2, oscillations in normal acceleration at the pilot station greater than ________ will be considered excessive for any Flight Phase. These requirements shall apply with the pitch control fixed and with it free.

REQUIREMENT RATIONALE (4.2.3)

The requirement prohibits limit cycles in the control system or structural oscillations that might compromise tactical effectiveness, cause pilot discomfort, etc. This requirement may be considered a relaxation of the requirement in 4.2.1 for positive damping at all magnitudes of oscillation. Its intent is to recognize thresholds below which damping is immaterial.

REQUIREMENT GUIDANCE

The related MIL–F–8785C requirement is paragraph 3.2.2.1.3.

The recommended value is 0.02g. Given the proper data, this threshold could be made a function of frequency in order to correspond more closely with human perception.

REQUIREMENT LESSONS LEARNED

Allowable normal acceleration oscillations have been decreased to 0.02 g from the 0.05 g of MIL–F–8785C. This is based on flight test experience with the B–1 (AFFTC–TR–79–2), which encountered limit cycle oscillations during aerial refueling, subsonic and supersonic cruise. A primary contributor was identified to be mechanical hysteresis in the pitch system. According to AFFTC–TR–79–2, "Flying qualities were initially undesirable due to this limit cycle." Normal acceleration transients in cruise were about 0.05 – 0.12 g, as figure 94 shows. The limit cycle was eliminated by installation of a mechanical shaker (dither) vibrating at 20 Hz.

5.2.3 Residual pitch oscillations—verification. Verification shall be by analysis, simulation and flight test.

VERIFICATION RATIONALE (5.2.3)

Limit cycle amplitude depends on characteristics of the actual hardware and software, and so may be different in simulations than in actual flight. Measurements of normal acceleration at the pilot's station should be made in the course of test flight to meet the other flying quality requirements.

VERIFICATION GUIDANCE

Residual oscillations are limit cycles resulting from nonlinearities such as friction and poor resolution. Negative static stability will contribute and low damping may augment the amplitude. Thus high speed, high dynamic pressure or high altitude may be critical. Residual oscillations are most bothersome in precision tasks.

VERIFICATION LESSONS LEARNED

4.2.5 Pitch trim changes. The pitch trim changes caused by operation of other control devices shall not be so large that a peak pitch control force in excess of 10 pounds for center–stick controllers or 20 pounds for wheel controllers is required when such configuration changes are made in flight under conditions representative of operational procedure. Generally, the conditions of table IV will suffice for determination of compliance with this requirement. With the aircraft trimmed for each specified initial condition, and no retrimming, the peak force required to maintain the specified parameter constant following the specified configuration change shall not exceed the stated value for a time interval of at least 5 seconds following the completion of the pilot action initiating the configuration change. The magnitude and rate of trim change subsequent to this time period shall be easily trimmable by use of the normal trimming devices. These requirements define Level 1. For Levels 2 and 3, the allowable forces are increased by 50 percent. __________

REQUIREMENT RATIONALE (4.2.5)

These frequently encountered pitch trim changes, if too large, can add to pilot workload at critical times during a mission.

REQUIREMENT GUIDANCE

The related MIL–F–8785C paragraph is 3.6.3.1.

Table XV gives the recommended conditions (For aircraft with variable–sweep wings, additional requirements should be imposed consistent with operational employment of the vehicle. Thrust reversing and other special features also need to be considered). These are the trim changes that, when larger than the limits specified, have been bothersome in the past. Crossfeeds and feedbacks in the stability and control augmentation system generally will reduce the magnitude of these trim changes. Wing downwash and vertical placement of the engines are two of the determining factors. For thrust reversing, configuration–dependent aerodynamics play an important role.

4.1.13 gives additional general trim requirements.

REQUIREMENT LESSONS LEARNED

The direction of the trim change can also be important, producing either helpful or unfavorable coupling. In any case the magnitude should not be excessive.

5.2.5 Pitch trim changes—verification. Verification shall be by analysis, simulation and flight test.

VERIFICATION RATIONALE (5.2.5)

The evaluation should be made in the manner expected in operational practice, rather than necessarily holding everything else constant.

VERIFICATION GUIDANCE

Initial trim conditions are listed in table XV.

VERIFICATION LESSONS LEARNED

TABLE XV. Pitch trim change conditions.

	Flight Phase	Initial Trim Conditions					Configuration Change	Parameter to be held constant
		Attitude	Speed	Landing Gear	High–lift Devices & Wing Flaps	Thrust		
1	Approach	$h_{o_{min}}$	Normal pattern entry speed	Up	Up	TLF	Gear down	Altitude and airspeed*
2				Up	Up	TLF	Gear down	Altitude
3				Down	Up	TLF	Extend high–lift devices and wing flaps	Altitude and airspeed*
4				Down	Up	TLF	Extend high–lift devices and wing flaps	Altitude
5				Down	Down	TLF	Idle thrust	Airspeed
6			V_{nco}	Down	Down	TLF	Extend approach drag device	Airspeed
7				Down	Down	TLF	Takeoff thrust	Airspeed
8	Approach		V_{nco}	Down	Down	TLF	Takeoff thrust plus normal cleanup for wave–off (go–around)	Airspeed
9	Takeoff			Down	Take–off	Take–off thrust	Gear up	Pitch attitude
10			Minimum flap–retract speed	Up	Take–off	Take–off thrust	Retract high–lift devices and wing flaps	Airspeed
11	Cruise and air–to–air combat	$h_{o_{min}}$ and $h_{o_{max}}$	Speed for level flight	Up	Up	MRT	Idle thrust	Pitch attitude
12				Up	Up	MRT	Actuate de–celeration devices	
13				Up	Up	MRT	Maximum augmented thrust	
14			Speed for best range	Up	Up	TLF	Actuate de–celeration device	

* Throttle setting may be changed during the maneuver.

Notes: – Auxillary drag devices are initially retracted, and all details of configuration not specifically mentioned are normal for the Flight Phase.
– If power reduction is permitted in meeting the deceleration requirements established for the mission, actuation of the deceleration device in #12 and #14 shall be accompanied by the allowable power reduction.

Supersedes pages 281 – 282 of MIL–STD–1797A

5.5.1.5 Time delay—verification. Verification shall be by analysis, simulation and flight test.

VERIFICATION RATIONALE (5.5.1.5)

In the end, flight test data or a flight–verified analytical model should be used to verify compliance.

A control surface rate limit may increase the equivalent time delay or roll–mode time constant as a function of the size of command.

VERIFICATION GUIDANCE

Appropriate values of ”cn will require equivalent system matching, as discussed above. See guidance for 4.5.1.1.

VERIFICATION LESSONS LEARNED

4.5.2 Pilot–in–the–loop roll oscillations. There shall be no tendency for sustained or uncontrollable roll oscillations resulting from efforts of the pilot to control the aircraft. The phase angle of the bank angle frequency response to roll stick force at the criterion frequency, . $_{c}$, shall be greater than or equal to _______. Furthermore, the requirements of 4.5.1.1, 4.5.1.3, 4.5.1.4, 4.5.1.5, 4.5.8.1, 4.5.9.2, and 4.5.9.3 must be met.

REQUIREMENT RATIONALE (4.5.2)

This roll–axis requirement is stated in addition to the general requirement of 4.1.11.6 to emphasize its importance for the roll axis and to allow incorporation of a more quantitative requirement.

REQUIREMENT GUIDANCE

The related MIL–F–8785C requirement is paragraph 3.3.3.

Recommended values:

The recommended minimum phase angle of the bank angle frequency response to the roll stick force at the criterion frequency, . $_{c}$, is –180′.

The value of . $_{c}$ is determined as follows:

$$. _{c} = (0.24 \text{ rad–oct/dB–sec})\ \overline{S} + 6.0 \text{ rad/sec}$$

where $\overline{S}$ is the average slope of $\left| \frac{(s)}{F_{as}(s)} \right|$ in dB/oct over the interval from 1 to 6 rad/sec.

This requirement is the Smith–Geddes PIO criteria extended to the lateral–directional axis. The origins of the Smith–Geddes criteria are traced in 4.2.2 Requirement Guidance, and discussions of the calculation of $\overline{S}$ and . $_{c}$ can be found there. Application in the lateral–directional axis is similar to that in the longitudinal axis, except that it is applied to $/F_{as}$ instead of to $''/F_{es}$.

The statement that requirements 4.5.1.1, 4.5.1.3, 4.5.1.4, 4.5.1.5, 4.5.8.1, 4.5.9.2, and 4.5.9.3 must also be met would seem to be redundant, since these are already requirements. However, recent history would seem to indicate that, because the term PIO does not appear in these requirements, the importance of these requirements in precluding PIO is not appreciated. Many recent PIO incidents can be traced directly to problems addressed by these requirements. Therefore, these requirements are repeated here in the PIO requirement to insure that their significance in precluding PIO tendencies is understood.

REQUIREMENT LESSONS LEARNED

The extension of the Smith–Geddes criteria to the lateral–directional axis was developed in AFWAL–TR–81–3090. In AFWAL–TR–81–3090, the lateral–directional criteria was used to analyze the YF–16, the X–15, and the M2–F2 and M2–F3 lifting bodies and also compared with results from handling qualities research projects with variable–stability aircraft: an approach and landing evaluation with the NT–33 (AFWAL–TR–81–3116), an investigation of reentry vehicle lateral–directional dynamics on the NT–33 (WADD–TR–61–147), and one configuration from lateral–directional studies on the Princeton Navion (Princeton University Report No. 727). Most of the data support the PIO criteria, and, in those cases where PIO was predicted but not encountered, handling qualities were usually poor.

See 4.2.2 for discussion of applicable considerations and data, in that case directed at longitudinal PIOs in general. The M2–F2 lifting body (NASA–TN–D–6496) encountered several divergent PIOs during flight testing. The primary cause was found to be the coupled roll subsidence/spiral mode (see Lessons Learned for 4.5.1.3).

Another cause of observed lateral PIO tendencies is the ” /” $_{d}$ effect noted and explained in figure 158 and also in Norair Rpt No. NOR–64–143. Another prevalent cause is associated with control–surface rate saturation. In this case the pilot tries to apply lateral control at a rate greater than the maximum surface rate, thereby getting out of phase if tight tracking is attempted. The quantitative aspects of such rate–limiting are given in the appendix of Norair Rpt No. NOR–64–143 and involve gain and phase decrements that are functions of the ratio of commanded to saturation rate.

PIOs on recent aircraft have been related to roll responses which are both too low (F–18) and too high (YF–16). These cases are discussed under 4.5.8.1 and 4.5.9.3. Control sensitivity, control surface rate limiting, control surface saturation, and (equivalent) time delay are critical factors in roll PIO.

5.5.2 Pilot–in–the–loop roll oscillations – verification. Verification shall be by analysis, simulation and flight test.

VERIFICATION RATIONALE (5.5.2)

This requirement should apply to all flight conditions and tasks, and to all Levels, since zero or negative closed–loop damping is to be avoided under all flight conditions and failure states.

VERIFICATION GUIDANCE

The existence of a PIO tendency is difficult to assess. A high–stress task such as approach and landing with a lateral offset, air–to–air tracking, or terrain following, may reveal PIO proneness. Demanding tracking tasks, aggressive control, sensitive response, proverse yaw, low dutch roll damping and long equivalent time delay are factors varying with flight condition which may tend to incite roll PIOs. Lateral acceleration induced on the pilot in rolling may contribute.

VERIFICATION LESSONS LEARNED

In a number of cases optimization of p/F_{as} in a fixed–base simulator has resulted in gross oversensitivity in actual flight.

2. Multiply the result by $N_{\Delta rp}/L_{\Delta as}$, i.e., $\Delta_{rp}(3) = Y_{CF}(3) \quad N_{\Delta rp}/L_{\Delta as}$

3. Compare $\Delta_{rp}(3)$ with table XLIV

7. If $0.03 \leq |N_{\Delta as}/L_{\Delta as}| \leq 0.07$, utilize the more conservative result from steps 5 and 6.

8. If the configuration does not meet the requirements, see figure 249 and table XLVII to determine the type of expected piloting problems.

9. In the end, the transfer functions should be identified from flight data.

VERIFICATION GUIDANCE

The flight testing to obtain ". and β t command should cover the range of operational altitudes and service speeds. As with roll rate oscillations (4.5.1.4), the critical flight conditions for compliance with this requirement should in general become apparent during the roll performance testing of 4.5.8.1. The most important flight conditions for compliance demonstration of either alternative are those with low $|\beta/.|_d$, less than 6.

An approximation for $|\beta/.|_d$ is

$$\left|\frac{\beta}{.}\right|_d , \left[\frac{(L_{.} \text{ o } Y_{.} L_r n \text{ oc} \quad d \; d L_r (L_{.} \text{ o } Y_{.} L_r n \text{ o} \quad d L_r}{d \; L_p \text{ oc} \quad d \; d L_p \text{ o} \quad d}\right] ,$$

$$\frac{k_z}{k_x} \frac{C_{\ell_{.}}}{C_{n_{.}}} \left[\frac{\frac{gb}{4(W/S)}\left[C_{y_{.}} \text{ o } k_z C_{n_r} \frac{k_z}{k_x}\frac{C_{\ell_{.}}}{C_{n_{.}}}\left(C_L \quad k_z C_{n_p}\right)\right]\frac{C_{\ell_r}}{C_{\ell_{.}}} \text{ o } \frac{gb}{8(W/S)} k_z\left(\frac{C_{\ell_r}}{C_{\ell_{.}}}\right) C_{n_{.}}}{\frac{gb}{4(W/S)}\left[C_{y_{.}} \text{ o } k_z C_{n_r} \frac{k_z}{k_x}\frac{C_{\ell_{.}}}{C_{n_{.}}}\left(C_L \quad k_z C_{n_p}\right)\right]\frac{C_{\ell_p}}{C_{n_{.}}} \text{ o } \frac{gb}{8(W/S)} \frac{k_z}{k_x}\frac{C_{\ell_p}}{C_{n_{.}}}}\right]$$

VERIFICATION LESSONS LEARNED

4.6.3 Pilot–in–the–loop yaw oscillations. There shall be no tendency for sustained or uncontrollable yaw oscillations resulting from efforts of the pilot to control the aircraft in the air or on the ground. Furthermore, the requirements of 4.6.2 must be met.

REQUIREMENT RATIONALE (4.6.3)

This requiremnt, in addition to the general requiremnt of 4.1.11.6, is inserted to provide more specific criteria for any task that might involve high–bandwidth control in yaw or lateral acceleration. An example might be yaw pointing for fine tracking.

REQUIREMENT GUIDANCE

The related MIL–F–8785C requirermnt is paragraph 3.3.3.

The statement that requirement 4.6.2 must also be met would seem to be redundant, since this is already a requirermnt. However, as with the corresponding requirements in the pitch and roll axes, because the term PIO does not appear in requirement 4.6.2, the importance of this requirement in precluding PIO may not be appreciated. Therefore, requirement 4.6.2 is repeated here in the PIO requirement to insure that its significance in precluding PIO tendencies is understood.

Due to the lack of a reliable quantitative measure, the requirement is written in terms of subjective evaluations. It is of course hoped that meeting the (other) quantitative requirements of this standard will prevent a lateral PIO. This requirement is identical to the roll–axis requirement of 4.5.2.

This requirement should apply to all flight conditions and tasks, and to all Levels, since zero or negative closed–loop damping is to be avoided under any flight condition or failure state. High–bandwidth yaw–control tasks are uncommon. The dynamic yaw response requirement (4.6.2.1) is designed to account for the need of rudder pedal in rolling, but may not cover all contingencies. Some direct sideforce modes may involve high–bandwidth yaw control; see AFWAL–TR–81–3027 and Sammonds, et al., for example.

REQUIREMENT LESSONS LEARNED

The pitch–axis PIO requirement, 4.2.2, discusses some causes of PIOs. Factors known to contribute to lateral–directional PIOs are large effective or equivalent time delays, excessive friction or hysteresis in the flight control system, and the “” /” $_d$” effect described at length in AFFDL–TR–69–72 (See 4.5.1.4 discussion). Depending upon the cause, ground–based simulation may or may not prove a useful investigation technique – often it does not.

5.6.3 Pilot–in–the–loop yaw oscillations – verification. Verification shall be by analysis, simulation and flight test.

VERIFICATION RATIONALE (5.6.3)

A precision closed–loop task, performed aggressively, is needed.

VERIFICATION GUIDANCE

The existence of a PIO tendency is difficult to assess. Therefore, no specific flight conditions or tasks are recommended, though a high–stress task such as approach and landing with a lateral offset, terrain following, air–to–ground tracking, or in–flight refueling (receiver) may reveal PIO proneness.

VERIFICATION LESSONS LEARNED