

AFFDL 1978 FLYING QUALITIES SYMPOSIUM & WORKSHOP
B-1 EXPERIENCE RELATED TO MIL-F-8785B*
AND PROPOSED REVISIONS

BY
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The B-1 is a large, flexible, low limit load factor, variable wing sweep aircraft with automatic and manual terrain following and air refueling capabilities.

During the B-1 development program, considerable analytical, flight simulation test, "iron-bird" test and flight test experience has been obtained relative to the flying qualities requirements of MIL-F-8785B and proposed revisions to this specification. Comments concerning experience relative to the requirements of particular paragraphs of MIL-F-8785B are presented below. Suggestions for possible requirements changes or for additional testing and validation are included. The specification paragraphs that are addressed are listed in Chart 1.

3.1.10.2 REQUIREMENTS FOR A/P FAILURE STATES - CHART 2

The requirements on the probability of encountering level 3 H.Q. due to failures are quite stringent. In the B-1, required mission success probability can be achieved with a (FCS) failure probability that is about 10 times that allowed by 3.1.10.2 for encountering level 3 H.Q. Since level 3 H.Q. are safe but probably not adequate for mission success and since, generally speaking, the same failure states that result in level 3 H.Q. also result in mission failure, it is recommended that the level 3 requirements be tied to mission success requirements.

If the initial design of an FCS/airplane combination does not satisfy 3.1.10.2 requirements, it is generally necessary to add more redundancy or some other degree of costly complexity. In order to avoid requirements that result in FCS overdesign, or to permit showing that a given system is not underdesigned, consideration might be given to allowing:

*MIL-F-8785B (ASG) Military Specification, Flying Qualities of Piloted Airplanes.

Contrails

(1) Use of average instead of maximum mission times in probability calculations. In a multiply redundant system the probability of failure is a function of mission time higher than 1st order. A system designed to meet failure requirements at the maximum mission time will be over designed when considering all missions and mission times.

(2) Including the probabilities of being at flight conditions where level 3 H.Q. are encountered. If certain failure modes result in level 3 H.Q. only at unusual flight conditions or those near the envelope extremes, the FCS will be overdesigned if it is assumed to be always operating at these conditions.

(3) The use of piloted flight simulation to evaluate flying qualities levels associated with various failure states. If certain failure modes degrade flying qualities, based on flight simulation, to a lesser extent than might be predicted from evaluation of specification parameters, then the FCS may be overdesigned unless these cases are recognized.

3.2.2.1.3 RESIDUAL OSCILLATIONS - CHART 3

During early flights on the B-1, pitch axis residual oscillation were observed at certain flight conditions that satisfied 3.2.2.1.3 requirements. At these conditions large amplitude pitch damping also satisfied 3.2.2.1.2 requirements, but pilots commented on inability to make small precise pitch changes. In a system with residual oscillation tendencies, damping ratio is a function of amplitude of control surface or aircraft motion as shown on the sketch of Chart 3. In such a system a pilot might try to make small control inputs in the range that result in poorly damped responses and consequently have difficulty in stabilizing the aircraft. Elimination of the residual oscillation solved the problem in the B-1 and may be the only answer for acceptable flying qualities.

3.2.2.2.1 CONTROL FORCES IN MANEUVERING FLIGHT - CHART 4

Early in the B-1 program various flight simulation programs were run that indicated the MIL-specification lb/g requirements were too high at various mission conditions, especially during terrain following. Specific comments are included on Chart 4. The aircraft FCS was initially set up to provide lb/g lower than specification requirements but subsequent augmentation gain changes, made because of structural mode coupling considerations, have resulted in lb/g characteristics that satisfy $N_L=3$ requirements but are less than $N_L=2$ requirements. During MTF flight testing lb/g values near 17 have been found to be too high based on fatigue considerations. Pilot comments relating to degree of fatigue associated with this force level are given on Chart 4. Future testing with lower force gradients is planned to determine desired levels but it is evident some provision needs to be made for special tasks.

3.3.1.2 ROLL MODE,

3.3.4 ROLL CONTROL EFFECTIVENESS,

3.3.4.2 AILERON CONTROL FORCES - CHART 5

These paragraphs, when used in combination, put some limits on allowed values for steady - state roll rate per roll stick force gradient but meeting these requirements doesn't insure good handling qualities. B-1 roll axis FCS parameter variation flight tests at several mission conditions show that both roll control characteristics considered sensitive and those considered to have high forces fall within allowed specification limits. Roll rate sensitivity, $\dot{\phi}/F$, seems to be a sufficiently important parameter to warrant a direct specification of allowed limits.

3.5.3 DYNAMIC CHARACTERISTICS - CHART 6

The intent of this paragraph is to insure a control system that has adequate dynamic response to allow favorable aircraft response control. It would seem logical to establish requirements on control force to aircraft response dynamics rather than on the FCS only. This is done for the pitch axis in the proposed paragraph 3.2.2.4.3. If similar paragraphs for the roll and yaw axes were established, 3.5.3 could be deleted.

The accompanying sketch on Chart 6 shows the δ/F transfer function for the B-1 that should be evaluated to show compliance with specification requirements rather than the open-loop stick force to surface transfer function that would be evaluated in an unaugmented aircraft. Characteristics that might be unsatisfactory open loop (no aero feedbacks) may be satisfactory when used with the aero feedbacks. In fact, during closed loop operations, stick force to surface phase angles may show lead rather than lag.

3.5.5.1 FAILURE TRANSIENTS - CHART 7

No B-1 in-flight augmentation failure transient experience has been obtained, but piloted flight simulation failure studies, based on aircraft hardware failure transient characteristics, provide some validation for proposed, 0.5g in 2 seconds allowable transient values in the pitch and yaw axes. Roll axis failures were too small to provide any validation. Simulation tests run at air refueling and terrain following test conditions showed that first and second pitch and yaw augmentation failure load factor transients are readily controlled by the pilot. Since level 3 flying qualities exist after second pitch and yaw augmentation failure transients (0.5g in 2 seconds) and since the pilots readily controlled these failure transients, it is reasonable to assume they could also have controlled the same failures with a level 1 or 2 flying qualities aircraft. Thus, for normal operations (not near the ground) the proposed allowable load factor transients seem acceptable. During terrain following, altitude loss may become a problem so that early failure detection is important.

During MTF operations, a pitch axis second augmentation failure is essentially unnoticed since the failure transient reflects on the TF display and is corrected by pilot action. During ATF operations, a second augmentation failure cannot be automatically responded to, since the automatic mode operates through the augmentation, and aircraft safety must be provided by pilot control through the mechanical control system. Failure detection time in the 1.5 to 2 seconds range has provided required safety for this type failure in the B-1.

3.5.6.1 TRANSFER TRANSIENTS - CHART 8

In the B-1, the stability augmentation can be shut off to allow pilot familiarization with unaugmented flight characteristics. Such shutoff results in the same control configuration as would exist following two augmentation failures in any one axis. At some flight conditions, this unaugmented configuration may provide level 3 flying qualities. At these conditions transients would satisfy failure state allowables but might not satisfy proposed transfer transient allowables. Perhaps the allowed transients should be based on the F.Q. level expected after the transfer.

NEW REQUIREMENTS - STRUCTURAL MODE COUPLING - CHART 9

During B-1 terrain following flight simulation studies, structural mode characteristics were included. It was found that pilot pitch control inputs cause structural mode motions at the cockpit which interfere with the pilot's control capability. The pilot is not trying to control the structural mode motion or control at the structural mode frequency but just unintentionally excites the modes. Modal motions are poorly damped and die out slowly. Pilot ratings improved significantly when a control input filter was used that prevented excitation of the structure or effectively decoupled the modal motions from the pilot inputs. Similar pilot/lateral structural mode coupling had been observed in earlier AMSA work. Some sort of new pilot/structural mode coupling requirement may be indicated as a result of these experiences.

Contrails

In a related phenomenon, it was also found that pilot ratings and control improved when structural mode motions were filtered out of TF commands displayed to the pilot.

FLYING QUALITIES REQUIREMENTS SYMPOSIUM
ROCKWELL LOS ANGELES COMMENTS
RELATED B-1 EXPERIENCE

Contrails

PARA. No.	TITLE
3.1.10.2	REQM'TS FOR AIRPLANE FAILURE STATES
3.2.2.1.3	RESIDUAL OSCILLATIONS
3.2.2.2.1	CONTROL FORCES IN MANEUVERING FLIGHT
3.3.1.2	ROLL MODE
3.3.4	ROLL CONTROL EFFECTIVENESS
3.3.4.2	AILERON CONTROL FORCES
3.5.3	DYNAMIC CHARACTERISTICS
3.5.5.1	FAILURE TRANSIENTS
3.5.6.1	TRANSFER TRANSIENTS
NEW	STRUCTURAL MODE COUPLING.

3.1.10.2 REQ'MTS FOR A/P FAILURE STATES

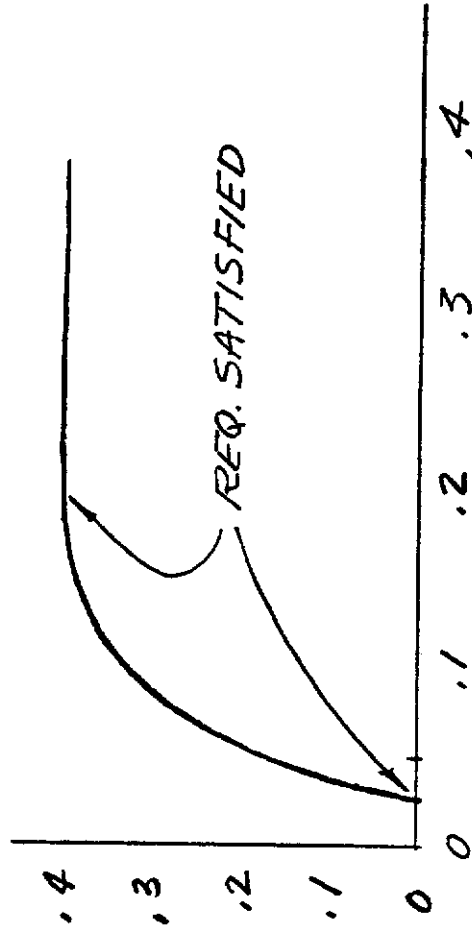
- CONSIDER TYING 3.1.10.2 LEVEL 3 REQ'MTS TO MISSION SUCCESS PROBABILITY ALLOWABLES
- B-1 MISSION SUCCESS CAN BE ACHIEVED WITH FCS FAIL. PROB. 10 TIMES THAT ALLOWED BY 3.1.10.2 FOR ENCOUNTERING LEVEL 3.
- AVOID REQ'MTS RESULTING IN FCS OVERDESIGN
 - ALLOW USE OF AVERAGE INSTEAD OF MAXIMUM MISSION TIMES IN PROBABILITY CALCULATIONS
 - ALLOW INCLUSION OF PROBABILITIES OF OPERATING AT FLIGHT CONDITIONS WHERE FAILURE MODES RESULT IN LEVEL 3 H.Q.
 - ALLOW USE OF PILOTED FLIGHT SIMULATION FOR DETERMINING H.Q. LEVELS ASSOCIATED WITH VARIOUS FAILURE STATES

Contrails

3.2.2.1.3 RESIDUAL OSCILLATIONS

- ① EARLY B-1 FLIGHTS - RESIDUAL OSCILLATIONS SATISFIED 3.2.2.1.3 REQ'NTS
- ② LARGE AMPLITUDE PITCH DAMPING SATISFIED 3.2.2.1.2 REQ'NTS
- ③ PILOTS COMMENTED ON INABILITY TO MAKE SMALL PRECISE PITCH CHANGES
- ④ REQ'NT REVISION MAY BE INDICATED

} DAMPING RATIO



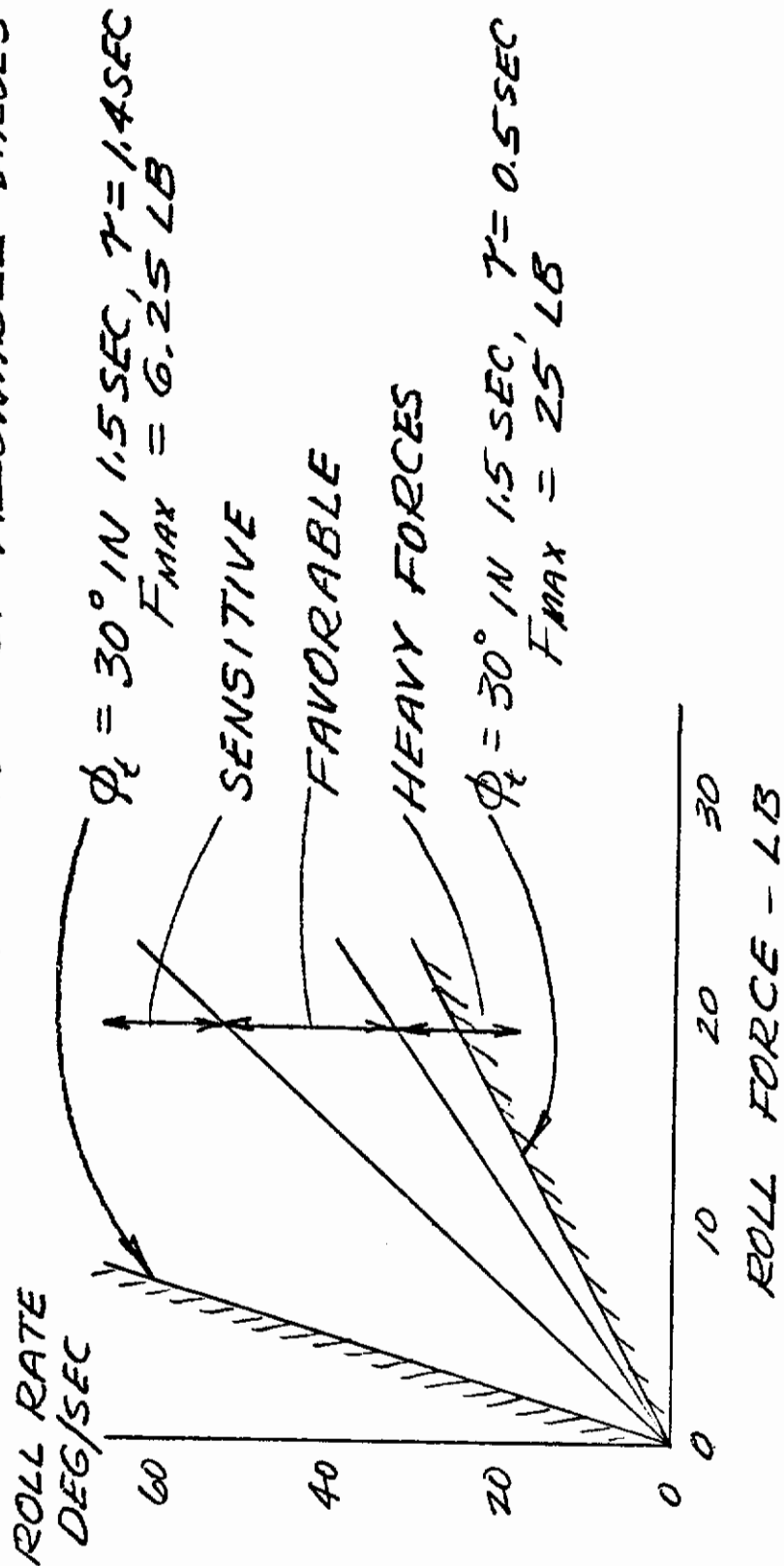
$\Delta\Omega_{2p}$ PILOT G'S

3.2.2.2.1 CONTROL FORCES IN MANEUVERING FLT.

- ③ NO PROVISION MADE FOR SPECIAL TASKS LIKE TERRAIN FOLLOWING
- ④ CONSOLIDATED PILOT COMMENTS - BASED ON FLIGHT SIMULATOR TESTS
 - 21 LB/G LEVEL 1 MIN. IS TOO HIGH FOR 2G A/C
 - 7-8 LB/G LEVEL 1 MIN. IS GOOD DESIGN GUIDE FOR 3G A/C
 - 4:4 LB/G MAY BE CONS. FOR TRAINED CP.
 - 3 LB/G MIN. SHOULD BE MAINTAINED FOR FAILURE MODES
- ⑤ B-1 MTF FLIGHT PILOT COMMENTS
 - 17 LB/G TOO HIGH BASED ON FATIGUE MEETS $n_L = 3$ REQMTS
 - BELOW $n_L = 2$ REQMTS
 - OVER RUGGED TERRAIN - 10 MIN. IS TRYING
 - COMPOSITE TERRAIN - 2 PILOTS SHARING TASK
 - SHORT TASK - 30 MIN.
 - MEDIUM TASK - 1 HR
 - LONG TASK - 2 HR
- ⑥ REDUCED FORCE GRADIENTS TO BE TESTED

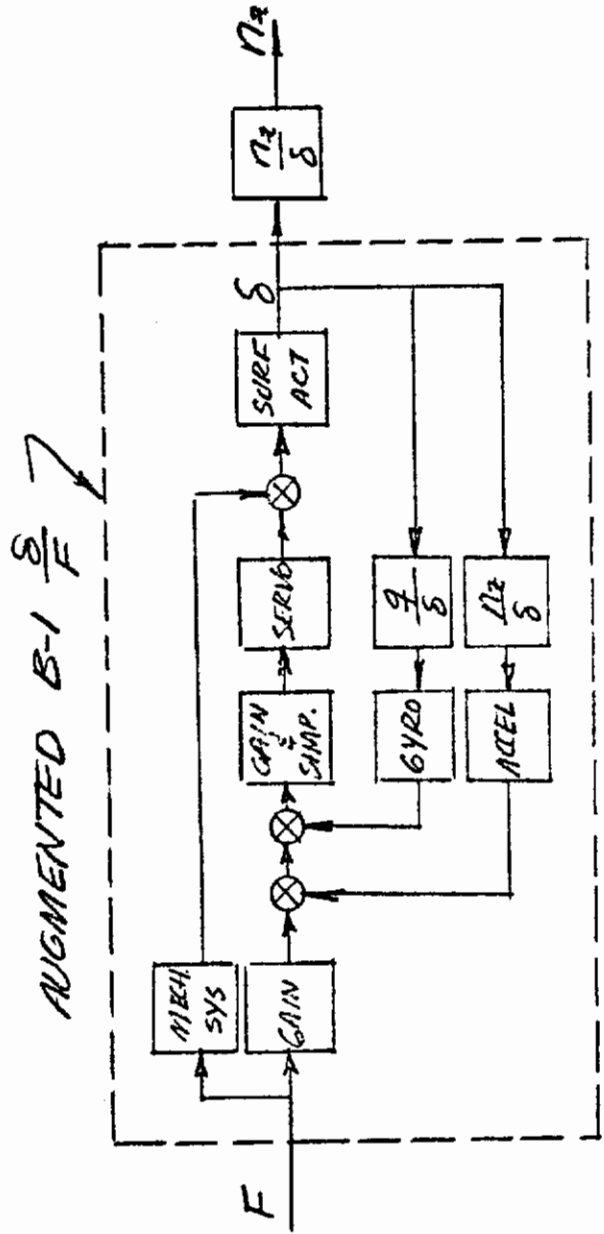
- 3.3.1.2 ROLL MODE
- 3.3.4 ROLL CONTROL EFFECTIVENESS
- 3.3.4.2 AILERON CONTROL FORCES

- ④ THESE PARAGRAPHS TEND TO DEFINE ALLOWED RANGE FOR $\dot{\phi}/F$
- ⑤ MEETING REQMTS DOESN'T INSURE GOOD H.Q. IMPORTANCE OF $\dot{\phi}/F$ MAY JUSTIFY DIRECT SPECIFICATION OF ALLOWABLE VALUES



3.5.3 DYNAMIC CHARACTERISTICS

- PITCH AXIS PHASE REQ. COVERED BY PROPOSED PARA. 3.2.2.4.3
- REQ'ITS FOR ROLL & YAW AXES CORRES. TO THOSE IN PROPOSED PARA. 3.2.2.4.3 WOULD BE MORE MEANINGFUL THAN THOSE IN 3.5.3
- WITH THESE CHANGES, 3.5.3 COULD BE DELETED
- AS 3.5.3 STANDS AUG. A/C CLOSED LOOP $\frac{\delta}{F}$ PHASE ANGLES MUST BE USED TO SHOW COMPLIANCE - NOT OPEN LOOP $\frac{\delta}{F}$



3.5.5.1 FAILURE TRANSIENTS

- ① B-1 FLIGHT SIMULATION EXPERIENCE TENDS TO VALIDATE PROPOSED REQ. IN PITCH & YAW AXES
- ② PITCH & YAW 1ST AUG. FAILURES
 - .2G AT END OF 2 SEC TRANSIENTS EASILY CONTROLLED
 - NO IMPROVEMENT REQ'D
- ③ PITCH & YAW 2ND AUG. FAILURES
 - .5G AT END OF 2 SEC. TRANSIENTS EASILY CONTROLLED
 - NO IMPROVEMENT REQ'D DURING MTF. FAILURE DETECTION TIME IMPROVEMENT REQ'D DURING ATF BECAUSE OF POSSIBLE ALTITUDE LOSS
- ④ ROLL AUG 2ND FAILURES
 - 2 DEG/SEC AT END OF 2 SEC TOO SMALL TO HELP VALIDATE PROPOSED REQ'T.

3.5.6.1 TRANSFER TRANSIENTS

- REQ'NT DOESN'T ALLOW FOR SPECIAL CASES
- B-1 AUGMENTATION CAN BE SHUT OFF FOR TRAINING PURPOSES
- AUG. SHUTOFF CORRESPONDS TO DOUBLE FAILURE
- CRITICAL FLT. COND. TRANSIENTS SATISFY FAILURE REQ'NTS BUT EXCEED PROPOSED 3.5.6.1 ALLOWABLES
- CONSIDER RELATING ALLOWED TRANSIENTS TO H.Q. LEVEL AFTER TRANSFER

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NEW REQ'MT - STRUCTURAL MODE COUPLING

- ① B-1 ABRUPT MTF PITCH CONTROL INPUTS CAUSE STRUCTURAL MODE EXCITATION AT COCKPIT
- ② SIMULATION TESTS SHOW DEGRADATION OF PILOT CONTROL CAPABILITY & RATINGS DUE TO PILOT/STRUCTURAL MODE COUPLING
- ③ RATINGS SIGNIFICANTLY IMPROVED BY DECOUPLING USING PILOT CONTROL INPUT FILTER.
- ④ SIMILAR PILOT/LATERAL STRUCTURAL MODE COUPLING OBSERVED IN EARLY AMSA WORK
- ⑤ NEW PILOT/STRUCTURAL MODE COUPLING REQ'MT MAY BE INDICATED

Contrails

Chick Chalk, Calspan: Does the aircraft have a 'g' limiter?

Answer: Not in the manual terrain following mode. No g limiter in any manual mode.

Tim Sweeney, ASD: Is it the forces or task of terrain following that is tiring?

Answer: Pilots complain of tired wrists.

Question: What is the structural mode frequency that was the problem?

Answer: The lowest fuselage vertical bending mode occurs at about $3H_z$.

Question: What is the frequency of residual oscillation?

Answer: Approximately $0.5 H_z$. Aircraft pitch short period frequency is in the range of 2-4 rad/sec.

Question: What is the nature of the pilot input filter?

Answer: Pilot electrical control input filters in the pitch & roll axes use first order lags with a time constant of 0.5 sec. A notch filter was used on the input to the terrain following display.