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A TECHNIQUE FOR MONITORING FLIGHT-TEST ENVELOPE EXPANSION

DONALD N. ARENTS

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December 1977

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APPLIED TECHNOLOGY LABORATORY
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Fort Eustis, Va. 23604

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USARTL-TN-28	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A TECHNIQUE FOR MONITORING FLIGHT-TEST ENVELOPE EXPANSION.		5. TYPE OF REPORT & PERIOD COVERED Technical Note
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Donald N. Arents		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Technology Laboratory, U. S. Army Research and Technology Laboratories (AVRADCOM) Fort Eustis, Virginia 23604		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L263211D157/17
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE December 1977
		13. NUMBER OF PAGES 15
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Flight test
Helicopter
Technique
Flight envelope

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A technique for monitoring flight-test envelope expansion is described. This "Smart Book" technique was used for the successful helicopter mode envelope expansion of the XH-59A Advancing Blade Concept (ABC) technology demonstrator aircraft. The technique contributed to the safety and success of the XH-59A program, provided control over the envelope expansion, and constituted a technical focal point that enhanced coordination between the Government and contractor test team members.

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INTRODUCTION

This technical note presents a technique for monitoring flight-test envelope expansion. This technique was used successfully in monitoring the envelope expansion of the advancing blade concept (ABC) technology demonstrator aircraft and can be applied to other aircraft envelope expansion programs of a similar nature.

The technique uses a compilation of ordinate/abscissa type plots which reflect the variation of selected aircraft and flight-test parameters as a function of pertinent variables (e.g., aircraft pitch attitude versus airspeed or vibratory pushrod loads versus airspeed). Predicted data is entered initially, and flight-test data is added as it becomes available. The correlation between the predicted and measured data is then used to manage the progress of the flight-test program. The entire collection of ordinate/abscissa type plots is referred to as the "Smart Book".

BACKGROUND

The Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory* awarded a contract in 1971 to the Sikorsky Aircraft Division of United Technologies Corporation to design, fabricate, and test a research aircraft to demonstrate the feasibility of the ABC (see Figure 1). The ABC employs two coaxial counterrotating rigid rotors, which compensate for retreating blade stall by making more efficient use of the rotor disk's advancing blade.

Flight testing of the ABC on an XH-59A aircraft began in July 1973. In August 1973, the number one XH-59A was extensively damaged in an accident relating to control system deficiencies.[1] Subsequent to the control modifications and prior to the initiation of flight tests with the remaining XH-59A aircraft, the Applied Technology Laboratory project management began employment of the "Smart Book" technique for monitoring and managing the ABC flight program.

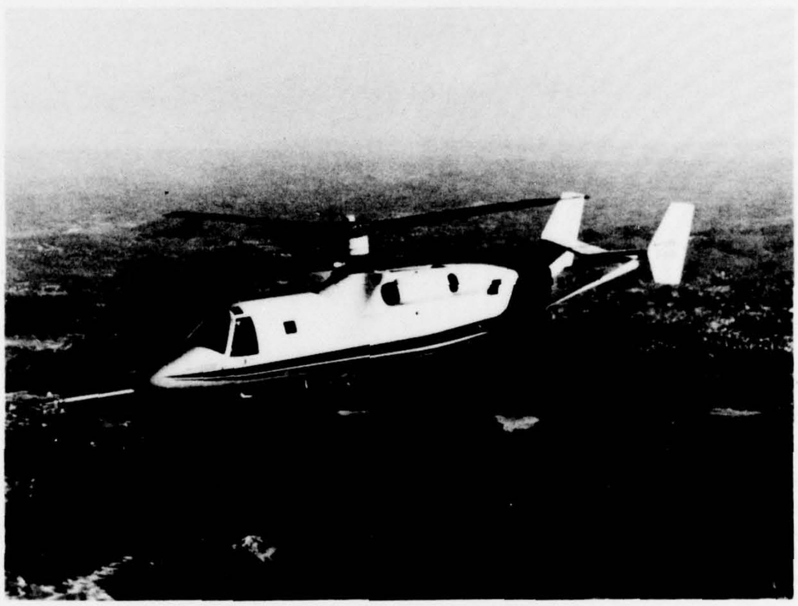

Figure 1. The XH-59A advancing blade technology demonstrator aircraft.

[1] Ruddell, A. J., *Advancing Blade Concept (ABC) Development*, Journal of the American Helicopter Society, Vol. 22, No. 1, January 1977.

*On 1 September 1977, the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, was redesignated the Applied Technology Laboratory, U. S. Army Research and Technology Laboratories (AVRADCOM).

THE ABC "SMART BOOK"

For the ABC "Smart Book", three categories of parameters were identified:

Category A - Parameters whose values were required to be predicted before flight.

Category B - Parameters whose values were to be predicted before flight and required acceptabie correlation with flight-test data as the flight envelope was being expanded.

Category C - Certain structural parameters which were important for safety-of-flight aspects. Based on structural fatigue tests and analyses, "abort" and "3σ" endurance limits were established for these parameters.

- The component "abort" limit is defined as that vibratory stress or load of sufficient magnitude to cause immediate concern and require prompt reduction, aircraft landing, and inspection of the overstressed item.

- The component 3σ endurance limit, which includes a three-standard-deviation reduction from the mean endurance limit, refers to that vibratory load or stress below which unlimited life can be expected.

Parameters could be added to all three categories. However, no parameters could be deleted from categories A and B of the "Smart Book". Category C parameters could be deleted or modified as testing progressed.

Initially, the parameters chosen for the ABC testing were:

Category A (28 parameters)

1. Eight upper and lower flatwise and edgewise blade stresses.
2. Pitch and roll attitudes.
3. Upper and lower rotor pitching and rolling moments.
4. Power required.
5. Longitudinal, lateral, directional, and collective control positions.
6. Longitudinal, lateral, directional, and collective control powers.
7. Blade tip clearance.
8. Upper and lower rotor pushrod loads.
9. Upper and lower rotor edgewise damping.

Category B (9 parameters)

1. Longitudinal, lateral, directional, and collective control positions.
2. Longitudinal, lateral, directional, and collective control powers.
3. Blade tip clearance.

Category B parameter values were required to correlate with predicted values and to remain within specified limits. In the ABC program, control positions were to be within ±50 percent of the control travel remaining or ±20 percent of the total control travel, whichever was less (see Figure 2). For all flight conditions, control power was to be within ±20 percent of the hover control power value. Measured clearance between upper and lower rotor blade tips was to be within ±50 percent of the predicted clearance, or within ±6 inches of prediction, whichever was less. The flight maneuver was to be aborted when the upper and lower rotor blade clearance reached a minimum of 10 inches. In the event the correlation limits were exceeded or trending indicated a rapid divergence from predictions, flight tests were to cease until a satisfactory explanation and substantiation of the reason for inadequate correlation were completed.

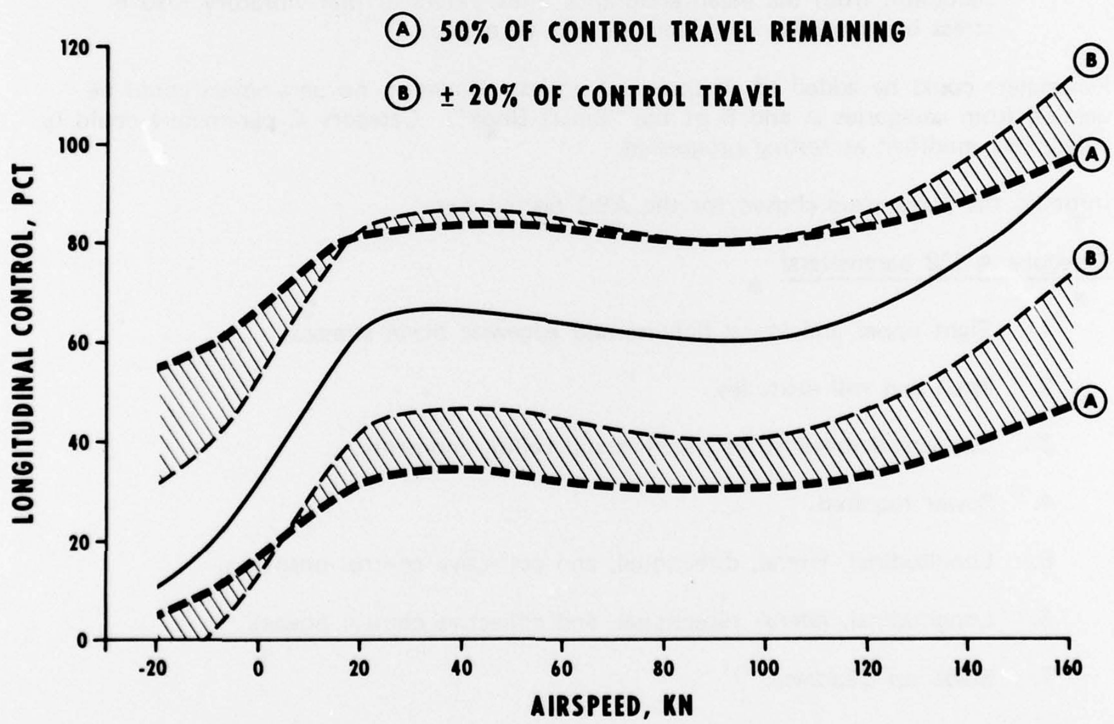

Figure 2. Allowable longitudinal cyclic deviation from prediction.

Category C (stress and load parameters)

1. Rotor blade stresses.
2. Upper hub/shaft stresses.
3. Lower hub/shaft stresses.
4. Primary servo rod loads.
5. Transmission case stresses.
6. Airframe skin, stringer, and fitting stresses.

Initially, the values of category C 3σ endurance structural limits were specified and exceedances were not permitted. After completion of the component fatigue testing, exceedances of the 3σ endurance limits were permitted provided the time above the limit was recorded in terms of cycle counts. Stresses above the abort limit required an immediate stop to flight testing and an inspection of the overstressed item.

FLIGHT-TEST PROCEDURES

The ABC flight-test procedures included comprehensive preflight and postflight briefings. Participants included designated members of the contractor's flight-test team, cognizant Government representatives, and chase/rescue flight crew. The standard flight-test procedures included discussion of the configuration changes, test limitations, chase/rescue, test techniques, and the test points to be flown. The preflight briefing included a page-by-page formal review of all the category A and category B and appropriate category C "Smart Book" parameters conducted by designated test team members and Government representatives. A looseleaf master copy of the "Smart Book" was maintained by the contractor's Chief of Test. The Army onsite representative maintained a copy of the "Smart Book", which was updated between flights to reflect additional data as it became available to correlate with the predicted curves.

It was a requirement that the Army onsite representative, who was present to the maximum extent possible while the aircraft was in flight status, verify the proper preparation and maintenance of the "Smart Book". A daily log of the program activities and events was maintained to permit continuity with several engineers acting consecutively in the capacity of the Army onsite representative. An engineer from the Navy Plant Representative Office provided support as needed.

FLIGHT-TEST APPLICATION

Initially, the predicted data were established for each parameter. The "Smart Book" category A and/or B identification was placed in the upper right-hand corner of each page to aid in identification of the plots. The master copy of the "Smart Book" was used to provide copies of the current status of various parameters during the envelope expansion. This provided current information required by engineers in various disciplines for engineering analyses. A category A parameter "Smart Book" plot is shown in Figure 3 as it appeared before any flight testing was accomplished. This plot shows lower rotor edgewise bending vibratory stress at the 70-percent blade radius location as a function of airspeed for different swashplate phase angles (Γ). Only predictions are shown on this plot. Swashplate phase angle (Γ) was to be varied in the flight program.

The parameter of longitudinal cyclic stick position was in both categories A and B and is shown in Figure 4 as it appeared at the end of the 80-knot envelope expansion. This parameter was of primary interest during the low-speed envelope expansion to 80 knots. The predicted curves are shown and the flight-test data points plotted. The allowable margins were also included to correspond with flight release restrictions. "Smart Book" plots for the low-speed envelope expansion to 80 knots are reported in Reference 2.

Trailing-edge stress was a "Smart Book" parameter in category C and is shown in Figure 5 with data points as it appeared during the high-speed pure helicopter flight testing. Stress is shown for three gage locations on the upper and lower instrumented blades. The 3σ endurance limit specified in the flight release is plotted and the strain gage location identification is included. Endurance and abort limits were designated in the flight release and in the "Smart Book".

[2] Groth, W. P., *XH-59A Low Speed Flight Test*, Sikorsky Engineering Report 69043, October 24, 1975.

EDGEWISE BENDING STRESS AT .7R STATION
LOWER ROTOR ½ PEAK-TO-PEAK VIBRATORY

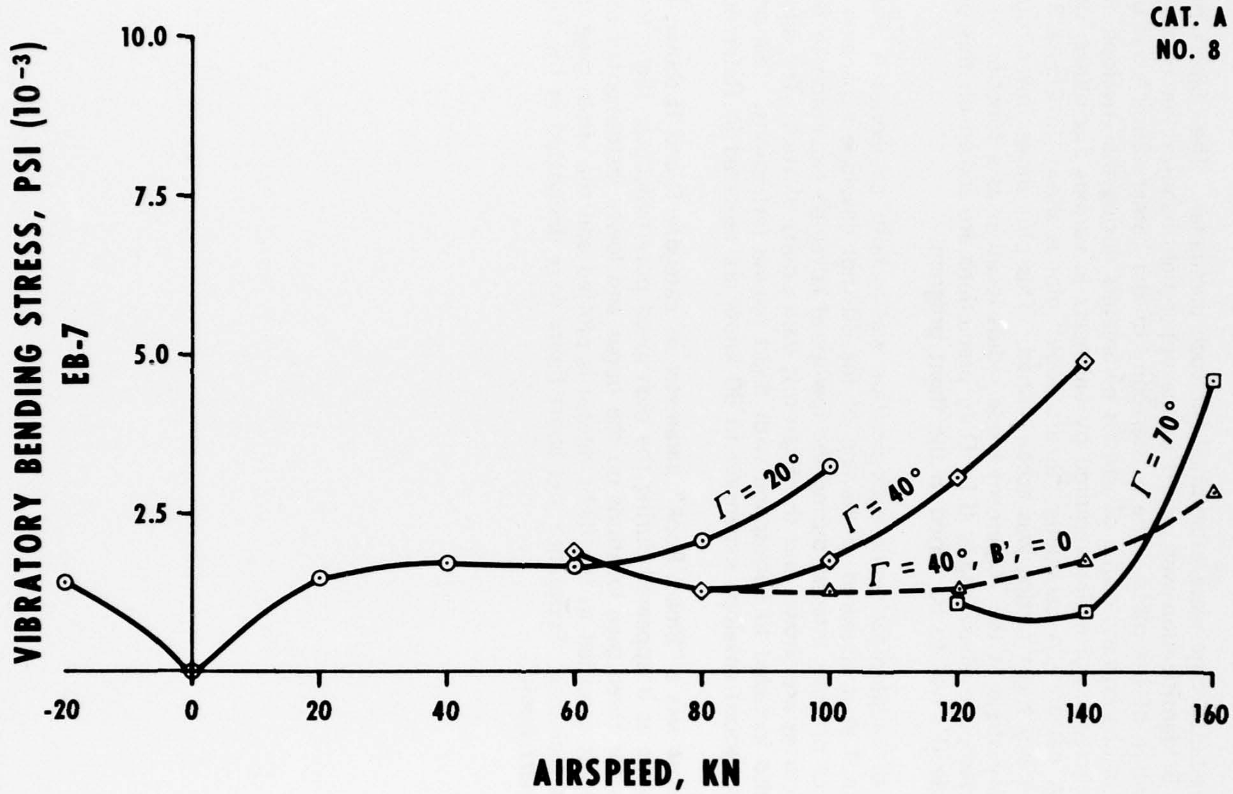

Figure 3. Example of a category A parameter.

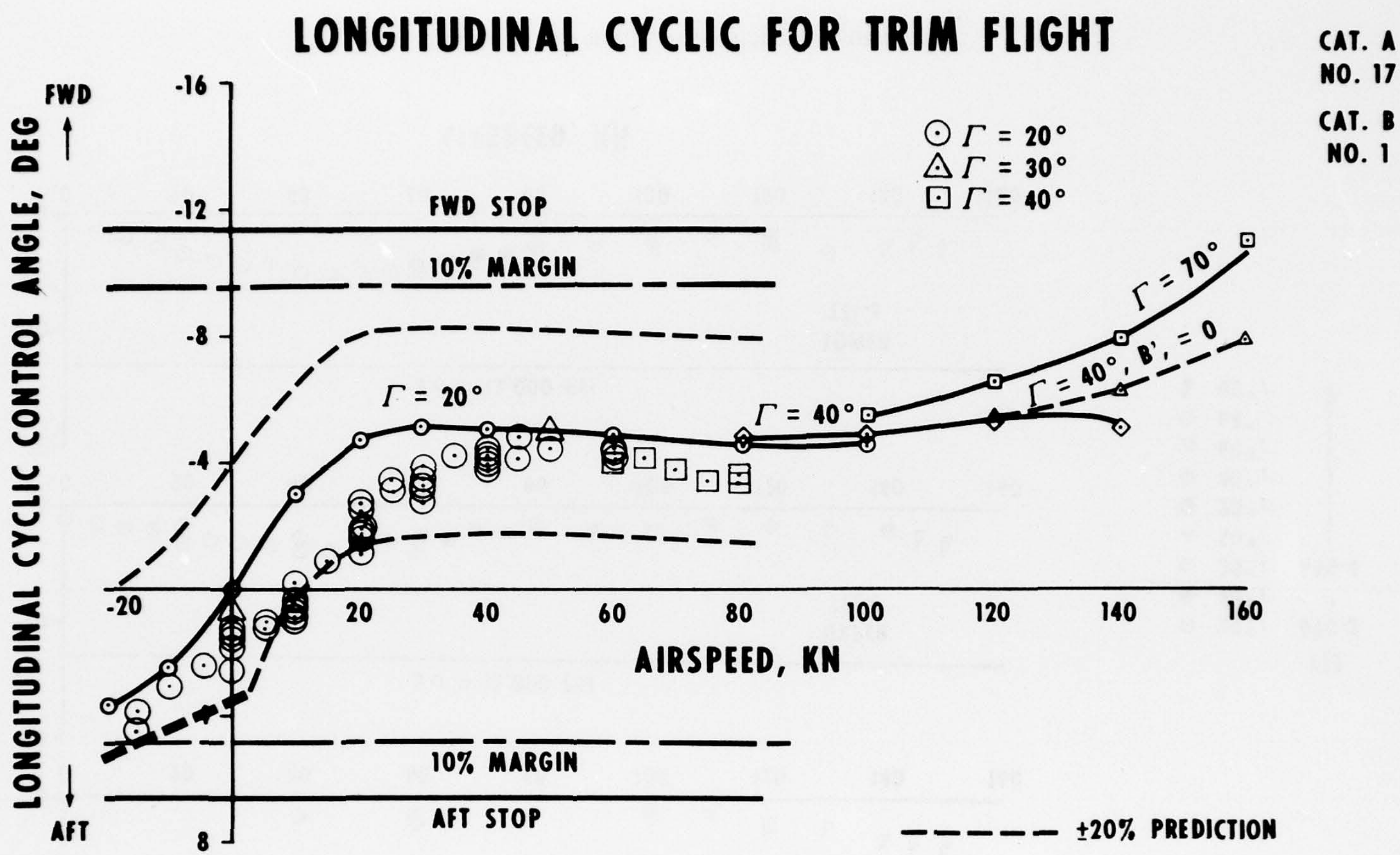

Figure 4. Example of category A and B parameters.

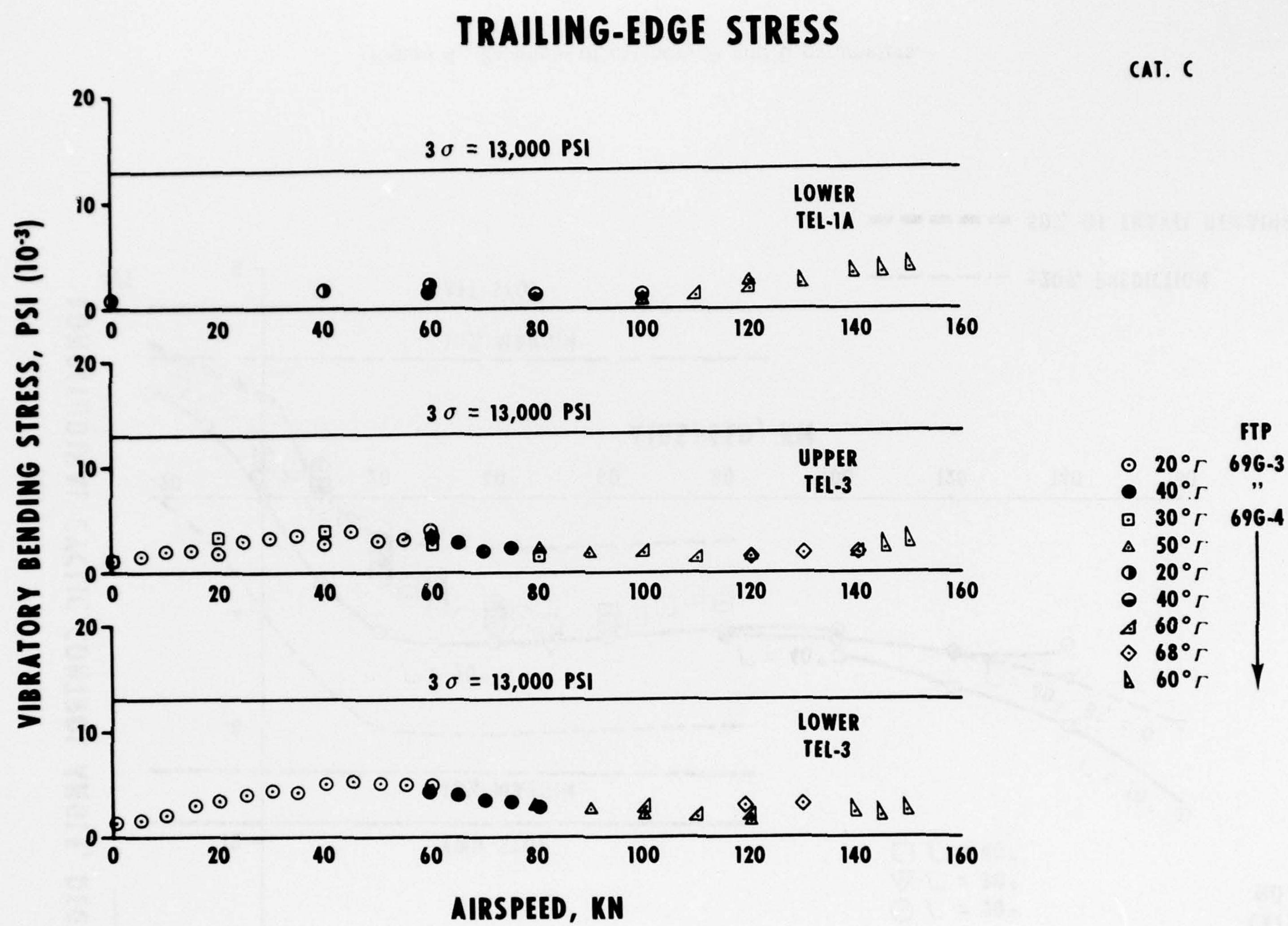

Figure 5. Example of a category C parameter.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The "Smart Book" technique contributed to the safety and success of the XH-59A pure helicopter envelope expansion. In addition to providing control over envelope expansion, it constituted a technical focal point that enhanced coordination and communication of the entire Government and contractor test team.

RECOMMENDATIONS

Based on the results of this effort, it is recommended that:

1. A "Smart Book" technique be used on flight-test programs where a significant envelope expansion is to be conducted.
2. A uniform method of dating "Smart Book" plots as they are updated be employed.
3. A calendar and flight number update notation be used.

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