NASA Technical Memorandum 86344

NASA-TM-86344 19850006524

FLIGHT TEST TECHNIQUE FOR EVALUATION OF GUST LOAD ALLEVIATION ANALYSIS METHODOLOGY

BOYD PERRY III

DECEMBER 1984

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

FLIGHT TEST TECHNIQUE FOR EVALUATION OF GUST LOAD ALLEVIATION ANALYSIS METHODOLOGY

Boyd Perry III
NASA Langley Research Center
Hampton, Virginia

ABSTRACT

A technique has been devised for gust load alleviation (GLA) flight testing that will approximate a turbulence-like excitation of the wing. An artificial excitation is produced by randomly deflecting inboard control surfaces on the wing, thereby producing incremental loads on the wing. This presentation covers the background and development of the flight test technique and analyses performed to date.

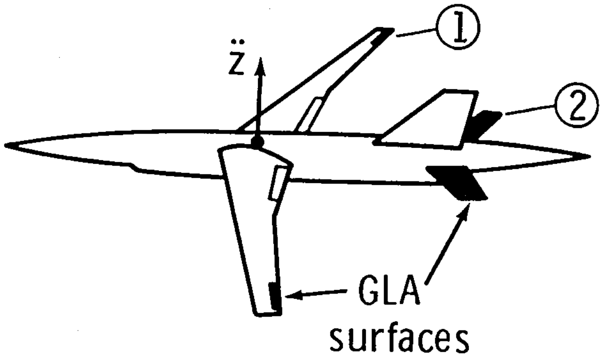
N85-14833 #

APPLICATION: DAST ARW-2

The flight test technique described in this presentation will be applied to the DAST ARW-2 vehicle depicted in this slide. The DAST (Drones for Aerodynamic and Structural Testing) Project is a NASA flight program jointly conducted by NASA-Langley and NASA-Ames/Dryden (ref. 1). In this project, aeroelastic research wings (ARW) are flight tested using modified Firebee target drones. The second research wing, ARW-2, is a fuel-conservative transport-type wing with a supercritical airfoil, low sweep angle (25° for the half chord), and high aspect ratio (10.3). DAST ARW-2 incorporates multiple active control functions: flutter suppression, gust load alleviation (GLA), maneuver load alleviation, and relaxed static stability. As indicated in the slide, the structural design of the wing and the design of the active control systems were performed under contract to NASA Langley by the Boeing Military Airplane Company. The flight test technique evolved from joint discussions between NASA and Boeing over the course of these contracts.

For the remainder of this presentation, the GLA will be the only active control system of interest. As depicted in the slide, the GLA uses vertical acceleration at the center of gravity as the feedback quantity and incorporates two symmetrically-deflecting control surfaces: an outboard control surface on the wing (denoted ① in the slide) and the all-moving horizontal tail (denoted ②). The inboard control surface on the wing will be discussed later.

APPLICATION: DAST ARW-2



- NASA flight program
- Fuel-conservative wing
- Multiple active controls

} Contract with Boeing Wichita

- Flight test technique evolved from joint discussions

MOTIVATION FOR FLIGHT TEST TECHNIQUE

During the GLA portion of flight testing there are two important objectives: to evaluate the analytical tools which predict airplane responses to turbulence and to validate the performance of the GLA system in atmospheric turbulence. Both of these objectives can be met if flight testing is conducted in atmospheric turbulence. The sketch in the left side of the block illustrates flight in turbulence, where for this simple illustration, only the vertical component, w_g, is indicated. However, for the DAST Project there are significant disadvantages in attempting to flight test in atmospheric turbulence. In order to appreciate these disadvantages, some background information on DAST flight operations is necessary. The following are typical of a single DAST flight:

- Flight test time is relatively short (30-45 minutes per flight, due to limited amount of fuel the vehicle can carry).
- Manpower expediture is relatively large (40-50 engineers, technicians, and pilots "spending" 600-800 manhours during the day before and day of the flight).
- Facility and equipment commitment is relatively large (a significant portion of Dryden Flight Research Facility, three airplanes, and a helicopter).

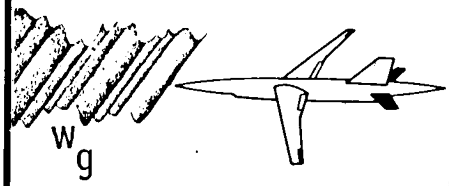
Considering this background information, the major disadvantage associated with flight testing in atmospheric turbulence is the uncertainty of even "finding" turbulence to fly in. Additionally, once found, the turbulence must be of sufficient duration to collect the required flight data. The possibility of not finding any or enough turbulence places both objectives in jeopardy and the manpower, facility and equipment investments necessary for each (short) flight makes even going looking for turbulence unattractive and impractical. Another disadvantage is the fact that, with flight testing in turbulence, the turbulence must be measured, which complicates and makes more complex the instrumentation and data acquisition systems on the vehicle.

All things considered, the decision was made to not search for atmospheric turbulence to flight test in. Therefore, as indicated on the bottom of the slide, an alternate excitation needed to be found.

MOTIVATION FOR FLIGHT TEST TECHNIQUE

Objectives:

1) Evaluate GLA analysis methodology
2) Validate performance of GLA in atmospheric turbulence

Atmospheric Excitation 	Difficult to "find" • uncertain • impractcal Must measure	Objectives in Jeopardy Complicates instr. and data acq.

Must look for an alternate excitation!

PROPOSED FLIGHT TEST TECHNIQUE

The proposed alternate excitation is illustrated in the left side of the block. The inboard control surfaces on the wing are deflected randomly (and symmetrically), producing random aerodynamic forces on the wing. (The symbol δ_g represents this deflection.) The GLA system will then operate to alleviate the incremental loads produced by this "artificial" form of excitation.

Moving across the block, compared to atmospheric turbulence, this form of excitation is enormously easy to "find" (a simple matter of a flight test engineer turning on a switch in the control room), which makes this form of excitation both certain and practical. However, there is a disadvantage associated with adopting this form of excitation and this is addressed in the right side of the block.

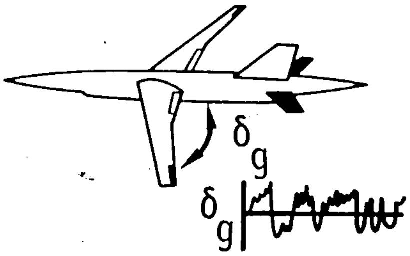
The disadvantage is that, with this alternate excitation, only objective no. 1 can be met. It is a straightforward task to modify the analytical tools such that, in the equations of motion and dynamic loads equations, the atmospheric-turbulence terms are replaced with artificial-excitation terms. With this modification, the analysis methodology may be evaluated by comparing analytical predictions with flight test results. Objective no. 2, validating the performance of the GLA in atmospheric turbulence, cannot be met directly. However, if the performance of the GLA can be validated with respect to artificial excitation, this will give confidence and be an indirect indication that the GLA will perform in atmospheric turbulence.

Due to the certainty and practicality of "finding" the artificial excitation and the fact that objective no. 1) can be met, it was decided to adopt the random control deflection as the excitation for GLA flight testing.

PROPOSED FLIGHT TEST TECHNIQUE

Objectives:

1) Evaluate GLA analysis methodology
2) Validate performance of GLA in atmospheric turbulence

Artificial Excitation  	Easy to "find" ● Certain ● Practical	Objectives No. 1) Can be met No. 2) Cannot be met directly

Adopt random control deflection as excitation.

DESIGN PHILOSOPHY OF ARTIFICIAL EXCITATION SYSTEM

The block diagram depicts DAST ARW-2 with the GLA system. Disturbance quantities w_g and δ_g represent the two forms of random excitation discussed in this presentation. Although shown together on the block diagram, during the discussion of this slide, it is to be understood that only one excitation will be present at a time. The remainder of this slide outlines the approach taken and considerations involved in designing the system which produces the artificial excitation.

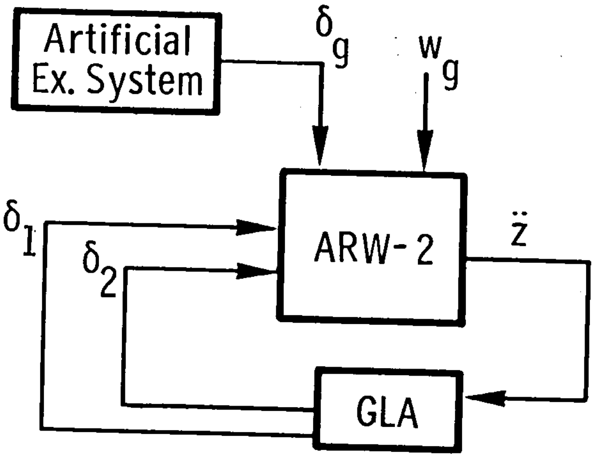
An important assumption is that the artificial excitation is a random process with known properties. Therefore, as with atmospheric turbulence, random process theory may be employed both in the reduction of flight test data and in analysis.

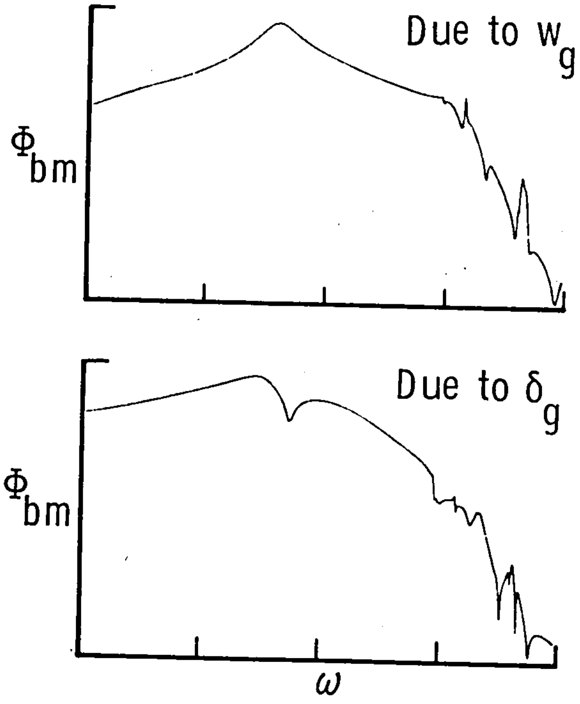
In switching to an alternate form of excitation it was recognized that, almost certainly, all airplane responses will change. Here, "responses" are analytical power spectral density functions (psd's) due to either excitation. The philosophy taken in the design of the artificial excitation system was to select a single response (wing root bending moment, because it is the quantity the GLA was designed to reduce), and attempt to do the following: by proper choice of artificial excitation system parameters to "match" this response due to δ_g as closely as possible to the same response due to w_g. This attempt is shown on the right side of the slide.

The top plot is a psd of wing root bending moment due to atmospheric turbulence, for GLA off, at Mach number 0.7 and altitude 15,000 feet. It is a log-log plot with approximately twelve log cycles along the ordinate (not shown) and four along the abscissa (corresponding to frequencies from 0.1 to 1,000 radians per second). The peak at about 3 rps represents the short period mode; the peaks beginning at about 100 rps are due to the flexible modes. The bottom plot is a psd of wing root bending moment due to artificial excitation (also for GLA off, same Mach number and altitude). The character of both psd's is the same: prominent short period mode and significant attenuation of the high-frequency flexible modes. On the basis of this similarity it was decided that the match was acceptable. The next slide shows how the artificial excitation system is implemented and the choice of parameters to produce this match.

DESIGN PHILOSOPHY OF ARTIFICIAL EXCITATION SYSTEM

- Artificial excitation is random process - known properties
- Employ random process theory
- Choose system parameters
- "Match" PSDs



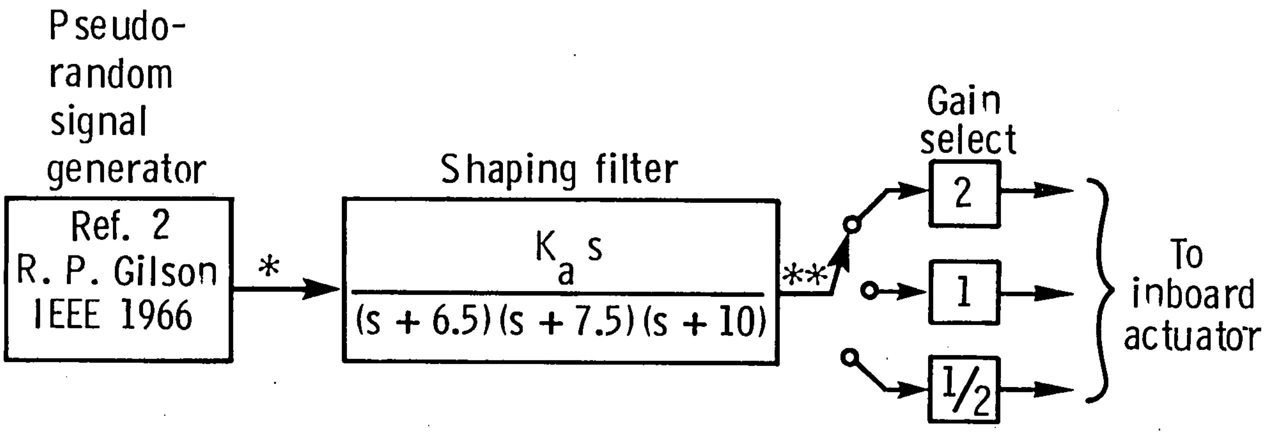


IMPLEMENTATION OF ARTIFICIAL EXCITATION SYSTEM

This slide illustrates the three elements of the artificial excitation system: a signal generator, a filter, and a gain. The signal generator (ref. 2) contains a 9-bit and an 11-bit shift register which are both driven by a 100-Hertz clock. The outputs of the two shift registers are combined, creating binary noise (a digital signal with magnitudes, in this case, of either +0.5 volt or -0.5 volt with duration of 0.01 seconds). The signal leaving the signal generator (*) has the characteristics indicated at the bottom of the slide. The sequence of +0.5's and -0.5's repeats in about three hours. This repetition means that the signal generator is actually periodic if left on for a long enough time, but it has certain properties of a random signal when left on for less than three hours. Hence, the term pseudo-random. In addition, the power spectral density function of the signal at this point will have constant amplitude from 0 to 10 Hertz (which means the signal approximates "white noise" over that frequency range). Next, the signal enters an analog shaping filter. As indicated in the slide, the filter has a first-order over third-order transfer function. Within the transfer function, gain K_a and time constants 6.5, 7.5, and 10 are the parameters chosen (refer to previous slide) to match the bending moment psd's. The signal leaving the shaping filter (**) is now analog and Gaussian. Next the signal passes through the gain selection and then finally to the hydraulic actuator which deflects the inboard control surface.

The electronic circuit boards implementing the artificial excitation system have been built by the contractor and tests on the circuitry have been performed at Langley. The next slide addresses the topic of these tests.

IMPLEMENTATION OF ARTIFICIAL EXCITATION SYSTEM



Characteristics:

*Sequence repeats after 174 minutes

*Digital noise "white" from 0 to 10 Hz

**Analog signal gaussian

CHARACTERISTICS OF ARTIFICIAL EXCITATION SYSTEM

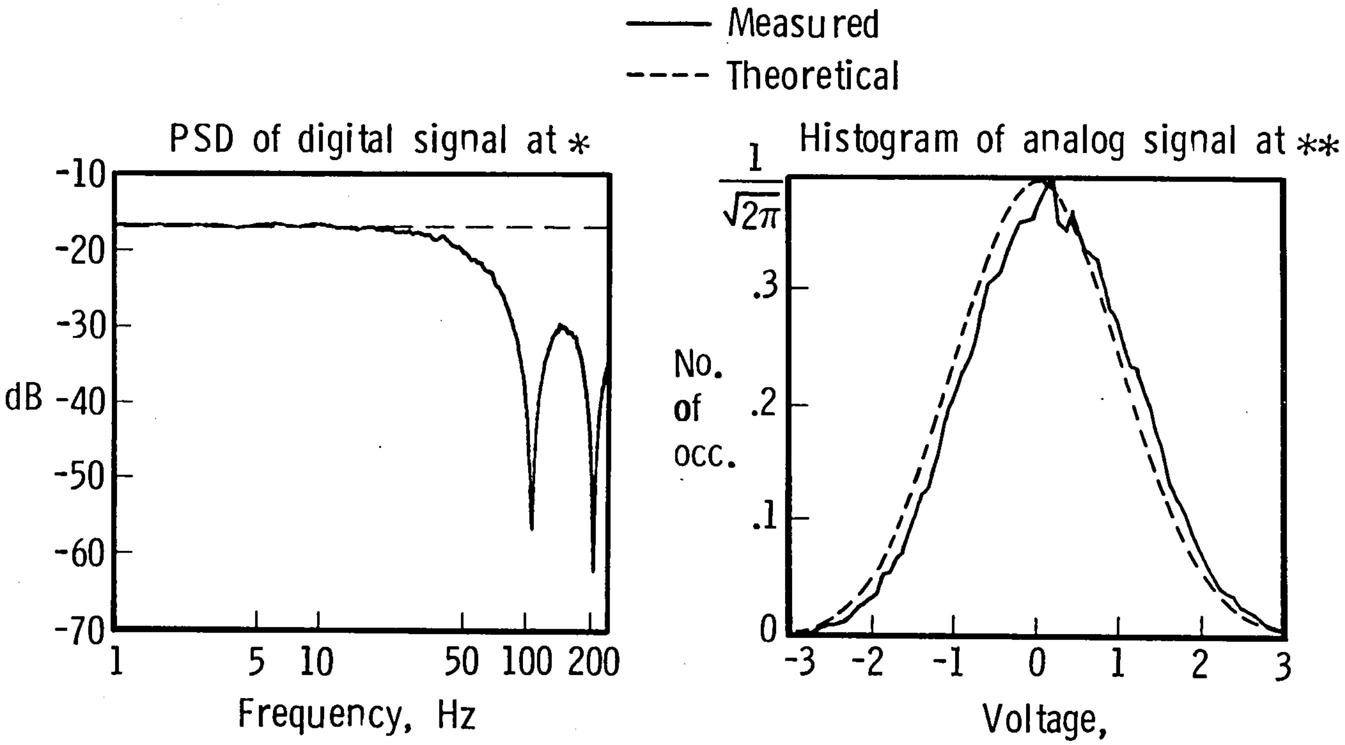
Tests were performed on the artificial excitation system circuitry to substantiate two of the characteristics claimed in reference 2 and listed on the bottom of the previous slide. Measured signals (about 20 minutes of data each) were processed by a signal analyzer and results are presented in this slide to answer the questions:

- o Is, in fact, the psd of the digital signal at * (see previous slide) "white" from 0 to 10 Hertz?
- o Is, in fact, the analog signal at ** (see previous slide) Gaussian?

The psd of the digital signal appears on the left. There is excellent agreement between the measured psd (solid line) and a theoretical white noise psd (dashed line) up to almost 20 Hertz. As a matter of interest, even at 50 Hertz there is only a 3 dB difference between measured and theortical psd's. Therefore, the answer to the first question above is "yes". On the right, a measured histogram of the analog signal (solid line) appears with a theoretical probability density function for a Gaussian distribution with zero mean (dashed line). The shapes of the two curves are in excellent agreement, confirming the claim that this analog signal is Gaussian. The small "shift" horizontally between the two curves merely indicates that the measured signal has a small non-zero mean.

These two comparisons support the assumption made in connection with the Design Philosophy slide, that the artificial excitation is a random process with known properties.

CHARACTERISTICS OF ARTIFICIAL EXCITATION SYSTEM

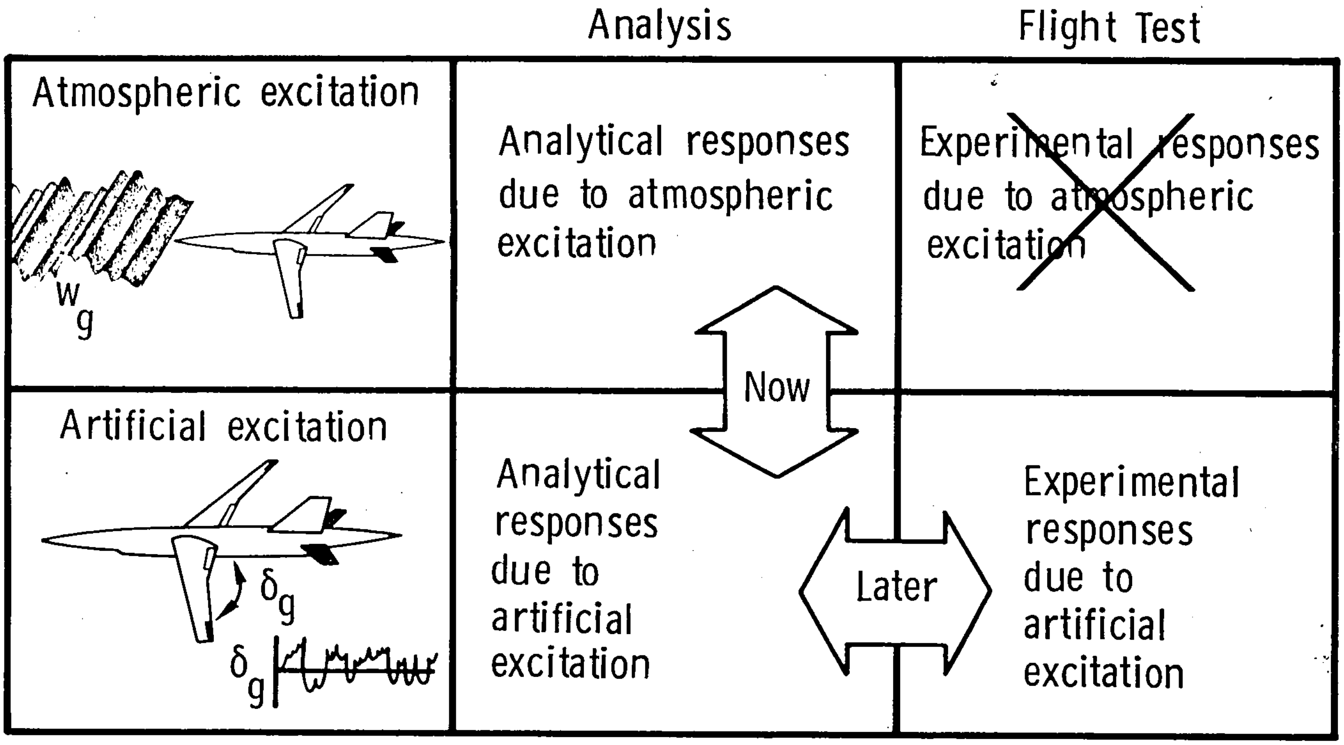


ANALYTICAL AND EXPERIMENTAL RESPONSES DUE TO EXCITATION

This slide serves as a transition to the final part of the presentation. It contains a matrix of analytical and experimental responses due to excitation. Sketches of ARW-2, seen in earlier slides, are repeated here. The top row corresponds to atmospheric excitation; the bottom row, to artificial excitation. One column represents analytical results; the other, flight test results. The large "X" in the upper right corner is a reminder that the decision has been made not to flight test in atmospheric turbulence.

The double-headed arrows indicate opportunities for comparisons. "Later" indicates that when DAST ARW-2 enters the flight-test phase, vehicle responses due to artificial excitation obtained during flight tests will be compared with analytical predictions. The evaluation of analysis methodology (objective no. 1) will be based on this comparison. "Now" indicates that the next slide contains comparisons of analytical responses.

ANALYTICAL AND EXPERIMENTAL RESPONSES DUE TO EXCITATION



	Analysis	Flight Test
Atmospheric excitation	Analytical responses due to atmospheric excitation	~~Experimental responses due to atmospheric excitation~~
Artificial excitation	Analytical responses due to artificial excitation	Experimental responses due to artificial excitation

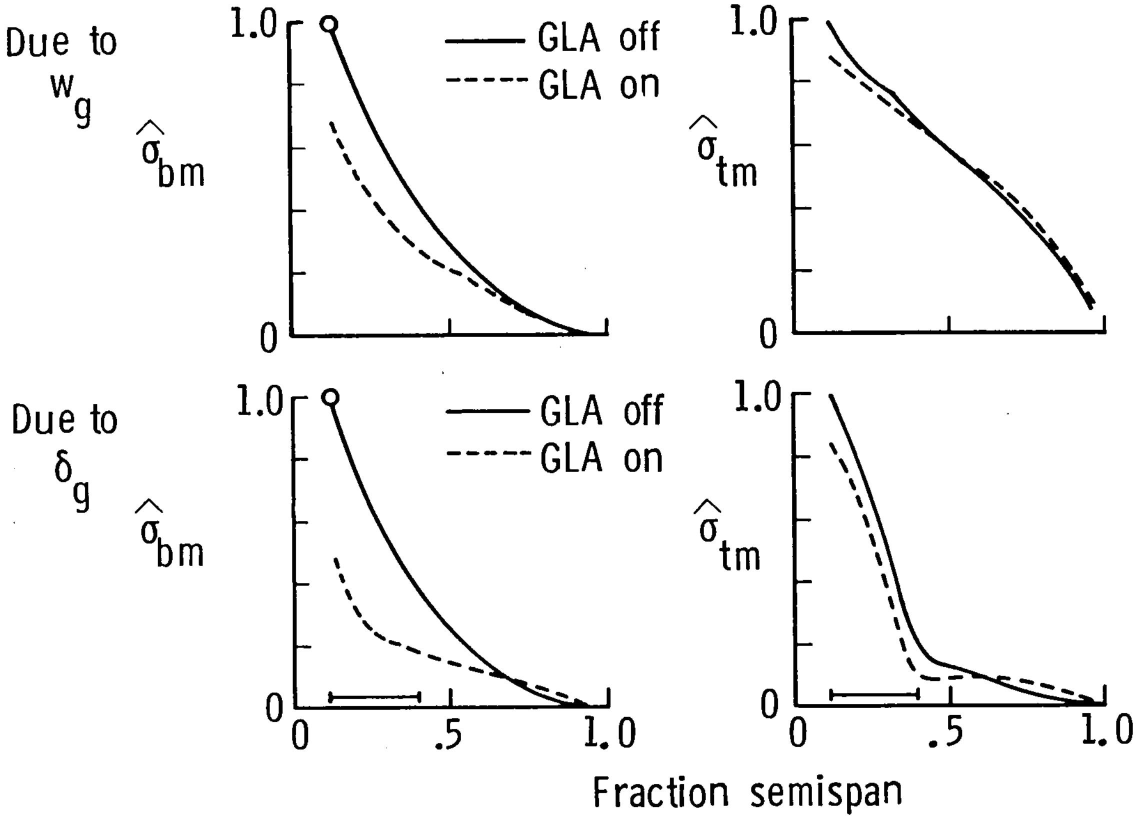
COMPARISON OF ANALYTICAL RESPONSES

The results presented in this slide are normalized root-mean-square (rms) vales of wing bending moment and wing torsional moment plotted versus fraction of wing semispan. The top two plots correspond to atmospheric turbulence as excitaiton. The bottom two correspond to artificial excitation, where the location of the artificial excitation surface is indicated above the abscissa. Both GLA-off and GLA-on results are presented. The DYLOFLEX system of computer programs (refs. 3 and 4) was used to compute these responses. Rigid-body, flexible, and control-system modes were present in the analyses. Unsteady aerodynamics were obtained at 14 reduced frequencies using a doublet lattice method. The analysis conditions for these results are Mach number 0.7 and altitude 15,000 feet.

Beginning with the bending-moment responses on the left side of the slide, the open circle symbols represent normalized wing-root bending moments (wrbm) and correspond to the two psd's presented in the Design Philosphy slide. As indicated on that slide, an effort was made to match the shape of the wrbm psd due to δ_g with that due to w_g. Although not shown in that slide (nor was it even attempted during the choosing of parameters) this match in bending-moment psd extends outboard along the span, and is reflected in the very similar shapes of the GLA-off $\hat{\sigma}_{bm}$ curves in this slide. In fact, were these curves plotted on the same set of axes, they would be almost coincident. With GLA on, there is a 30% reduction in wrbm due to w_g and a 50% reduction due to δ_g. Even though these reductions are different in magnitude, the overall character of the GLA-on curves (with respect to their respective GLA-off curves) is similar: reduction inboard, small increase outboard.

Moving to the torsional-moment curves on the right and comparing the w_g results with the δ_g results, the overall shapes are obviously different. The w_g curves decrease approximately linearly moving out the span; the δ_g curves do not, but show the strong effect of the artificial excitation surface in generating torsional moments inboard. However, there are similarities between w_g and δ_g results when the GLA-on curves are compared with their respective GLA-off curves: 12%-15% reductions at the root, increases outboard.

COMPARISON OF ANALYTICAL RESPONSES



CONCLUSIONS

A flight test technique has been presented for evaluation of GLA analysis methodology. It has been decided to adopt an artificial excitation (random symmetric deflection of inboard wing control surfaces) as an acceptable alternative to atmospheric turbulence. This artificial excitation allows objective no. 1 to be met directly and objective no. 2 to be met indirectly.

CONCLUSIONS

- Flight test technique presented for evaluation of GLA analysis methodology
- Artificial excitation acceptable alternative to atmospheric turbulence
- Objective no. 1 can be met directly
- Objective no. 2 can be met indirectly if objective no. 1 successful

REFERENCES

1. Murrow, H. N.; and Eckstrom, C. V.: Drones for Aerodynamic and Structural Testing (DAST) - A Status Report. J. of Aircr., vol. 16, no. 8, Aug. 1979, pp. 521-526.

2. Gilson, R. P.: Some Results of Amplitude Distribution Experiments on Shift Register Generated Pseudo-Random Noise. IEEE Transactions on Electronic Computers, Dec. 1966, pp. 926-927.

3. Perry, Boyd III; Kroll, Richard I.; Miller, Ronald D.; and Goetz, Robert C.: DYLOFLEX: A Computer Program for Flexible Aircraft Flight Dynamic Loads Analyses With Active Controls. J. Aircr., vol. 17, no. 4, Apr. 1980, pp. 275-282.

4. Miller, R. D.; Kroll, R. I.; and Clemmons, R. E.: Dynamic Loads Analyses System (DYLOFLEX) Summary. Volume I: Engineering Formulation. NASA CR-2846-1, 1979.

1. Report No. NASA TM-86344

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Flight Test Technique for Evaluation of Gust Load
Alleviation Analysis Methodology

5. Report Date
December 1984

6. Performing Organization Code
505-33-43-08

7. Author(s)
Boyd Perry III

8. Performing Organization Report No.

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, Virginia 23665

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, DC 20546

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes
Presented at the Aeroservoelasticity Technical Specialists Meeting at Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, OH from October 2 through Octiber 4, 1984.

16. Abstract

A technique has been devised for gust load alleviation (GLA) flight testing that will approximate a turbulence-like excitation of the wing. An artificial excitation is produced by randomly deflecting inboard control surfaces on the wing, thereby producing incremental loads on the wing. This presentation covers the background and development of the flight test technique and analyses performed to date.

17. Key Words (Suggested by Author(s))
Flight Test Technique
Gust Load Alleviation

18. Distribution Statement
Unclassified - Unlimited
Subject Category 05

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	21	A02

N-305

For sale by the National Technical Information Service, Springfield, Virginia 22161