NASA Technical Memorandum 89455

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(NASA-TM-89455) VISUAL DISPLAY AND ALARM SYSTEM FOR WIND TUNNEL STATIC AND DYNAMIC LOADS (NASA) 10 p CSCL 14B
N87-20298
Unclas
G3/09 45448

April 1987

National Aeronautics and
Space Administration

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Presented at the 33rd International Instrumentation Symposium,
Las Vegas, Nevada, May 3-8, 1987.

VISUAL DISPLAY AND ALARM SYSTEM FOR WIND TUNNEL STATIC AND DYNAMIC LOADS

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ABSTRACT

A wind tunnel balance monitor and alarm system developed at NASA Ames Research Center will produce several beneficial results. The costs of wind tunnel delays because of inadvertent balance damage and the costs of balance repair or replacement can be greatly reduced or eliminated with better real-time information on the balance static and dynamic loading. The wind tunnel itself will have enhanced utility with the elimination of overly cautious limits on test conditions.

The microprocessor-based system features automatic scaling and 16 multicolored LED bargraphs to indicate both static and dynamic components of the signals from eight individual channels. Five individually programmable alarm levels are available with relay closures for internal or external visual and audible warning devices and other functions such as automatic activation of external recording devices, model positioning mechanisms, or tunnel shutdown.

Keywords: Wind tunnel balance, loads monitor, bargraphs, alarm system.

INTRODUCTION

For many years the six-component strain-gage balance has been the primary instrument for obtaining force and moment information from models in wind tunnels. Sting-mounted internal balances in particular have evolved into complex and delicate systems of strain-gaged flexures.

The typical six-component internal balance measures model forward and aft lift forces, forward and aft side forces, drag force, and rolling moment. The lift forces can be combined to produce pitching moment and the side forces can be combined to produce yawing moment. The forces and moments are sensed by strain gages mounted on flexures that connect model load points to the balance structure. The only contact between the model and the wind tunnel model support system is through the balance at these specific load points.

Quite often, balances are designed and built for a specific program; indeed, sometimes it takes a program for which no existing balance is suitable to provide the impetus for the construction of a new one. More to the point, each balance is very nearly unique. Seldom are more than two built to the same set of specifications.

As might be expected with any complicated and delicate one- or two-of-a-kind device, broken or damaged balances are very costly and time-consuming to repair. The balance repair costs are in addition to the costs resulting from the time and effort needed to install a replacement balance during a particular wind tunnel test. In extreme cases there may be no direct or even marginally suitable replacement for a particular balance.

Consequently, it is desirable to protect balances from damage both outside and inside wind tunnels. Though transportation hazards may be somewhat uncontrollable, modern instrumentation techniques and hardware make it possible to develop and construct useful and versatile devices to protect balances or other devices from overload conditions inside the wind tunnel by properly monitoring the status of the balance loads.

A second, but no less important, reason for building an up-to-date balance monitor is to expand the envelope of usable wind tunnel conditions. Without a real-time indication of static and dynamic balance loading, test engineers must necessarily be conservative in their choice of running conditions. A test schedule may call for tunnel parameters that may not be allowed because of limited information regarding balance loading. Accurate real-time static and dynamic loads information allows better use of the tunnel operating envelope with confidence that the balance will not be damaged.

The purpose of this paper is to describe the Balance Load and Alarm Monitor System (BLAMS) that has been developed at the NASA Ames Research Center to prevent damage to wind tunnel balances due to test operations.

DESIGN CONSIDERATIONS

The goal of the balance monitoring system is to provide the test engineer with the current balance load status with respect to the maximum rated load (or full scale) for each balance gage. The current load status for each gage consists of two parts: the static load and the dynamic or time-varying load. They can be considered respectively as the "DC" and the "AC" portions of the total signal from each gage.

The signal from each balance gage passes through a four-pole filter (whose bandwidth is DC to 1 Hz) in the analog signal-conditioning circuitry of the wind tunnel data system. This stage separates the DC portion from the total signal. For a standard data point recorded digitally by the data system, each of the six filtered balance signals is sampled 100 times; it is then averaged to yield one value for each gage. The dynamic portion of the signal (wide-band AC) has rarely been used except in a balance monitoring mode with an oscilloscope or oscillograph. The wind tunnel data system was not designed to be capable of using or displaying the balance dynamic signals in a balance protection mode.

For a balance monitoring system to be truly useful, static and dynamic load components must be displayed separately and be easily identifiable. An important consideration is the ease with which a test engineer is able to set up and calibrate the system for a particular balance and model combination. The system must have provision for comparing the balance signals to a programmable algorithm that determines the various levels of the multiple alarms and programmable relay closures that trigger external devices. Equipped with this real-time information, the engineer can make intelligent decisions concerning the conduct of the wind tunnel test with regard to the safety of both the balance and the model being tested.

DESIGN FEATURES

The BLAMS shown in Figure 1 was designed around a 32-bit 68000 microprocessor to meet many requirements. The system was designed as an eight-channel unit to accommodate the six gages of a strain gage balance with two spare channels for signals from other sources. It uses two LED bargraphs to indicate the loads on each balance channel. One bargraph in each pair represents the static component from a single gage and the second represents the dynamic component from the same gage. Each vertical bargraph is 10 in. high and is composed of 101 LEDs representing plus and minus 100% of full scale or maximum rated load. The resolution of each bargraph is thus 2% of full scale of either polarity.

Green-colored LEDs are used for the static component bargraph while red-colored LEDs are used for the bargraph that depicts the dynamic component. The center or zero point of each scale is shown by an LED of the opposite color (red shows the static zero point and green shows the dynamic "zero" point), giving the viewer a good visual reference for the neutral points on each bargraph. These lights also serve in the dual capacity of indicating the system on/off status.

The colored analog bargraph display is complemented by a four-place-plus-sign digital readout that shows the voltage of the static component of the signal from each gage. This DC voltage reading can be compared directly to the static data signal recorded by the wind tunnel data system, allowing for any time lag. Because it is intended as an all-purpose device, the RMS voltage of the dynamic component can also be displayed on the digital readout through the use of a two-position color-coded switch (green for static, red for RMS).

The wide-band balance signals that are supplied by the data-system analog signal-conditioning amplifiers must be filtered by the BLAMS before their use to drive either type of bargraph. The passband of the static data signal is DC to 2 Hz with a 24-dB/octave rolloff, while that of the dynamic data signal is 1 Hz to 5 kHz. As noted previously, the wind tunnel data system has a passband of DC to 1 Hz for the static data it records digitally, so there normally will be good agreement between the tunnel system and BLAMS, even though their respective signal paths are different. The 2-Hz bandwidth of BLAMS was chosen deliberately to afford a somewhat faster response time for the visual monitor.

A sample analog input signal and the corresponding bargraph representations for four successive sample periods (τ) are shown in Figure 2. The magnitude of the static data sample is recorded at the center of each sample period, as shown. As for the dynamic data, the BLAMS senses both positive and negative signal peaks and displays them on the dynamic display bargraphs. These positive and negative peaks are based on a "zero" reference level that is defined as the magnitude of the static component during each sample period. It will be noted that, while the static data bargraphs (green) will show only zero-to-positive or zero-to-negative data for any single sample period, the dynamic data bargraphs (red) will show both positive and negative peaks at the same time.

These peaks are displayed on the dynamic bargraph as the highest and lowest values (with respect to the static component) seen by the circuitry during each sample period. The bargraph update rate (the inverse of the sample period) is adjustable from 4 times/sec to 16 times/sec. The green LED in the center of each red bargraph can be thought of as the highest (if positive) or the lowest (if negative) illuminated LED on the corresponding static data bargraph. (This is illustrated in Figure 2.)

BARGRAPH SCALING

Automatic scaling for each balance component is easily accomplished by BLAMS during the initial setup for each test. The balance calibration laboratory at Ames furnishes a value in volts for the maximum rated output for each balance gage. This number is based on maximum rated load, gage excitation, and signal amplification. During the test setup the engineer uses the keypad on the BLAMS front panel to input the maximum rated signal voltage for each balance channel. Each bargraph pair is then proportioned automatically in the BLAMS microprocessor to indicate 100% load at the maximum rated signal voltage for its respective balance channel.

Figure 3 shows the algorithm used to define the maximum allowable values of combined static and peak dynamic loads. The algorithm chosen to describe balance overload conditions is simple, but it is based on many years of experience. It is felt that a static loading to 110% of maximum rated load with no dynamic loading is acceptable. With the addition of dynamic load, however, the limit of acceptability, as defined by the algorithm, has a straight-line slope from that point (110% static, zero dynamic) to 50% static and 50% peak dynamic. A peak dynamic load of 50% is the maximum allowable for any condition of static load, as shown by the algorithm.

The dynamic component bargraphs have two options for scaling. The first option is based on the same system as the static data bargraphs, but because the dynamic components of the various signals are often much smaller in magnitude than the static components, provision has been made for additional gain at the engineer's discretion. Though normally a virtually nonexistent dynamic component is the desired condition, there may be times when the engineer wants to see a representation of it on the display. Also, when used to display signals from other sources, extra gain for the dynamic component may be even more useful. Gain steps of one, two, four, and eight have been provided in the BLAMS, with a seven-segment digital readout to indicate gain.

The second mode of dynamic scaling is somewhat more complicated, but may turn out to be the preferred method for monitoring balance loads. It is based on the difference between the static component value and the maximum allowable value, as defined by the algorithm in Figure 3. For each update period this difference is used as the full-scale value for the dynamic component. The positive and negative peaks (dynamic data) are always presented as a percentage of the total available margin between the static value and the maximum allowable value as defined by the algorithm for combined loading. For example, if the static load for a single update period is 80% of full scale, a line drawn upward from that point on the diagram intersects the maximum allowable line of the algorithm at the 25% level for dynamic peak data. For that update period, then, the full-scale value for the dynamic bargraph (red) is 25% of the full-scale value inserted into the BLAMS memory for that particular channel. Thus, the maximum allowable value for static plus dynamic data for that sample period is 105% of the full-scale value.

It can be seen that the scale of the dynamic bargraph can change during each update period. Remember, though, that the static data signal bandwidth is only DC to 2 Hz, so there will not be large changes between the adjacent update periods, which range from 1/4 sec to 1/16 sec, depending on the current program in the microprocessor memory. As the static component gets larger, the effect is to magnify the dynamic component representation on its bargraph since its full-scale value becomes smaller. At 50% static load, full-scale dynamic load on the bargraph is also 50%, but at 90% static load, the full-scale dynamic value on the bargraph is 17%. It is important to realize that the combination of the static and dynamic loads is an arithmetic sum, not a vector sum as might be implied by the diagram. The digital gain readout indicates "A" for "Auto" when the BLAMS is in this mode.

ALARM MODES

The multiple alarm levels used in the BLAMS are all based on the algorithm illustrated in Figure 3. At the programmed update rate, the microprocessor continually sums the static data signals and the dynamic peak signals of the same polarity and compares the totals to the alarm algorithm. Whenever the absolute value of the total exceeds any one of the preset alarm conditions, one or more of the several modes of alarm are triggered. If desired, the engineer or technician can display the static data plus the dynamic data together (as a reconstructed total signal) on the static data bargraph by pushing a button on the front panel. This will show how close the signal is to the allowable limits at any time, especially before proceeding into more dangerous portions of the test program.

The first level of alarm is shown in Figure 3. When the total signal from any one of the balance components intrudes into the alarm zone of the algorithm, the two bargraphs associated with that component begin to blink. For any alarm mode to be activated, over-limit conditions must occur in four successive update periods to eliminate the triggering by random spikes. Once activated, the blinking condition will continue for 5 sec. after the last trigger condition and then automatically revert to the normal display. The blinking condition is triggered anywhere along the line defined by the endpoints: 40% dynamic load, zero static load, and zero dynamic load, 80% static load, as shown in Figure 3.

The next stage of alarm, also shown in Figure 3, occurs at slightly higher levels. Here the blinking display is supplemented by an audible warning buzzer. There are also five independently programmable relays for triggering external devices at any preset level. Some examples of devices that might be utilized are cameras, oscillographs, tape recorders, angle-of-attack reduction mechanisms, and, possibly, tunnel fast-stop relays.

The BLAMS functions can all be programmed or modified at will through the use of an Apple Macintosh personal computer. Functions that can be reprogrammed include the alarm algorithm shape, the visual and aural alarm levels, the alarm relay closure levels, the update rate (or sample time) of the LED displays, and the alarm trigger conditions. If, with experience or for special conditions or tests, it becomes desirable or necessary to change the parameters, this can be accomplished easily with minor changes in standard subroutines. A software security lock can easily be implemented in the Macintosh program to prevent unauthorized parameter changes. Space has been provided on the front panel for affixing a set of user instructions and for listing the functions and parameters in the current microprocessor program.

BLAMS BLOCK DIAGRAM

The block diagram of one channel of the BLAMS unit in Figure 4 shows both analog and digital circuit components. The wide-band signal from the signal-conditioning system (whether from a balance channel or other source) is first separated into separate components by using various filters: positive or negative static signal (DC to 2 Hz), positive and negative dynamic signals (1 Hz to 5 kHz), and wide-band signal (1 Hz to 20 kHz). The wide-band signal is next converted to a DC analog of the signal RMS value.

The static and RMS signals are then sampled by a variable-rate, 12-bit-plus-sign data-acquisition system whose sample rate can be varied from 4 to 16 times/sec. The positive and negative dynamic signals are sampled by a digital peak detector at the rate of 12,500 samples/sec.

The 68000 microprocessor receives the sampled data and information from the switches and interrupts and processes them according to the current program. The appropriate commands are then sent to the display drivers for data presentation on the BLAMS front panel LED displays. The processor also sums the static data and the dynamic peak data, compares the results with the algorithm in memory, and triggers the various alarms and relays at their respective programmed levels.

CONCLUSIONS

A wind tunnel balance loads monitor has been developed at Ames Research Center which closes a large gap in monitoring capability. The device makes no attempt to define balance fatigue-cycle lifetime, but it will enable test engineers and technicians to protect balances from overload conditions much more easily. At the same time, the wind tunnel operating envelope can be used to greater advantage by having a more precise control on balance margin of safety.

In addition to its future as a primary instrument for monitoring balance component signals in as many as seven different wind tunnels, its very nature as a wide-band analog device with a programmable monitoring function suggests that it may find important applications in any number of instrumentation systems used at Ames. These may include pressure transducer, strain gage, accelerometer, hot-wire anemometer, or even thermocouple systems, or a mixture of any of these. This is particularly true when applied to any critical system that needs a full-time monitor with alarm and shutoff capability.

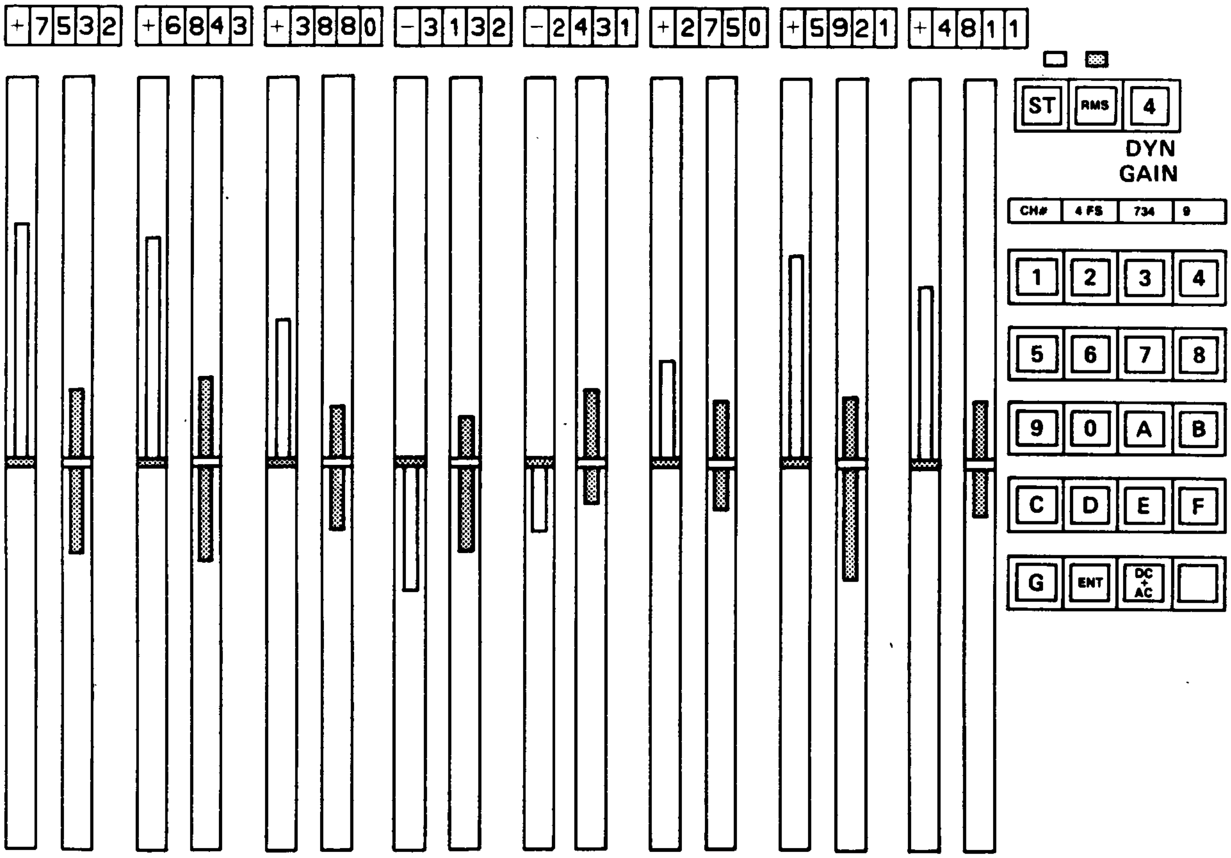

Figure 1 – BLAMS Front Panel With Simulated Loads.

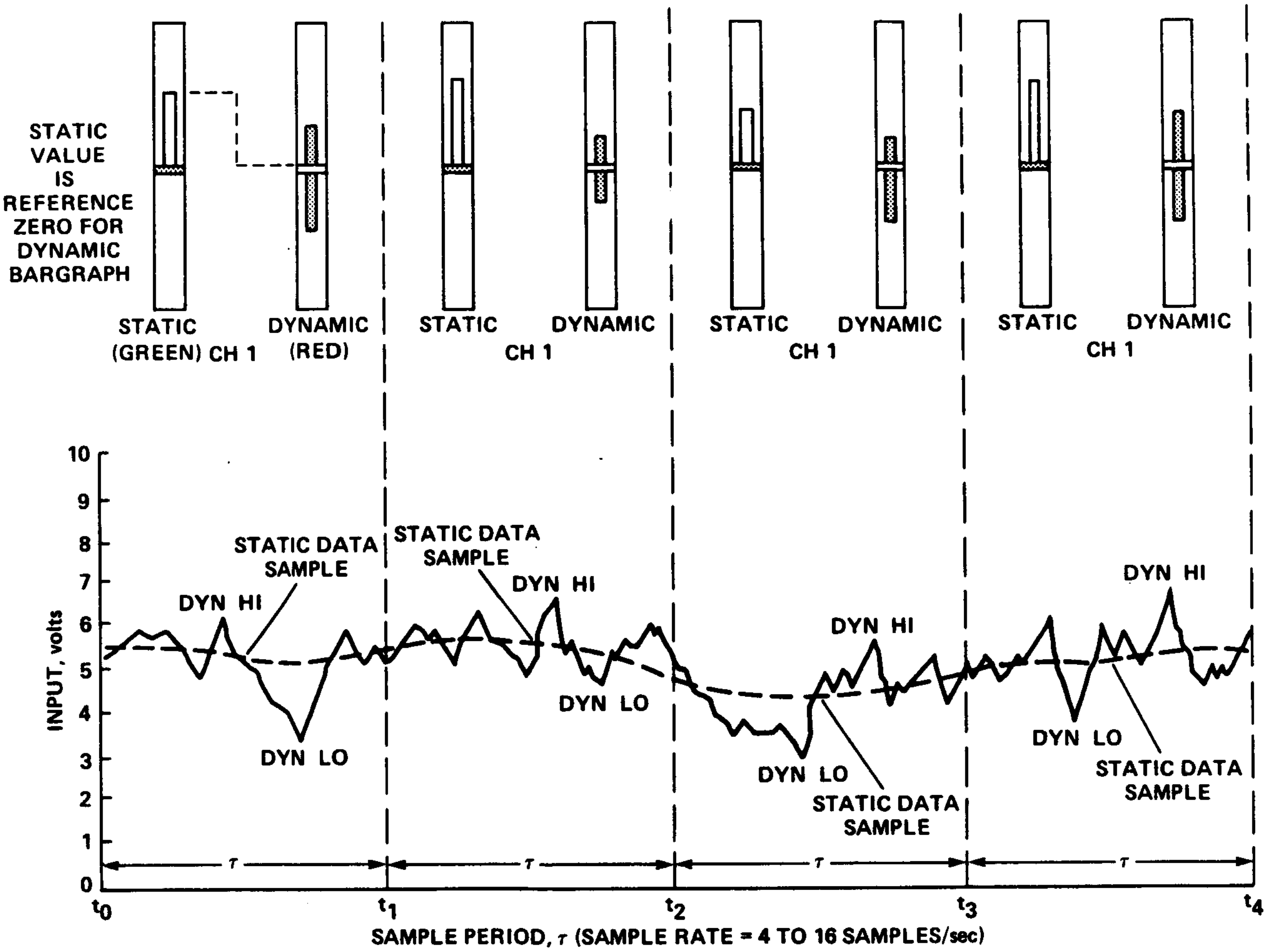

Figure 2 – Analog Input and Bargraph Representations for Four Successive Sample Periods.

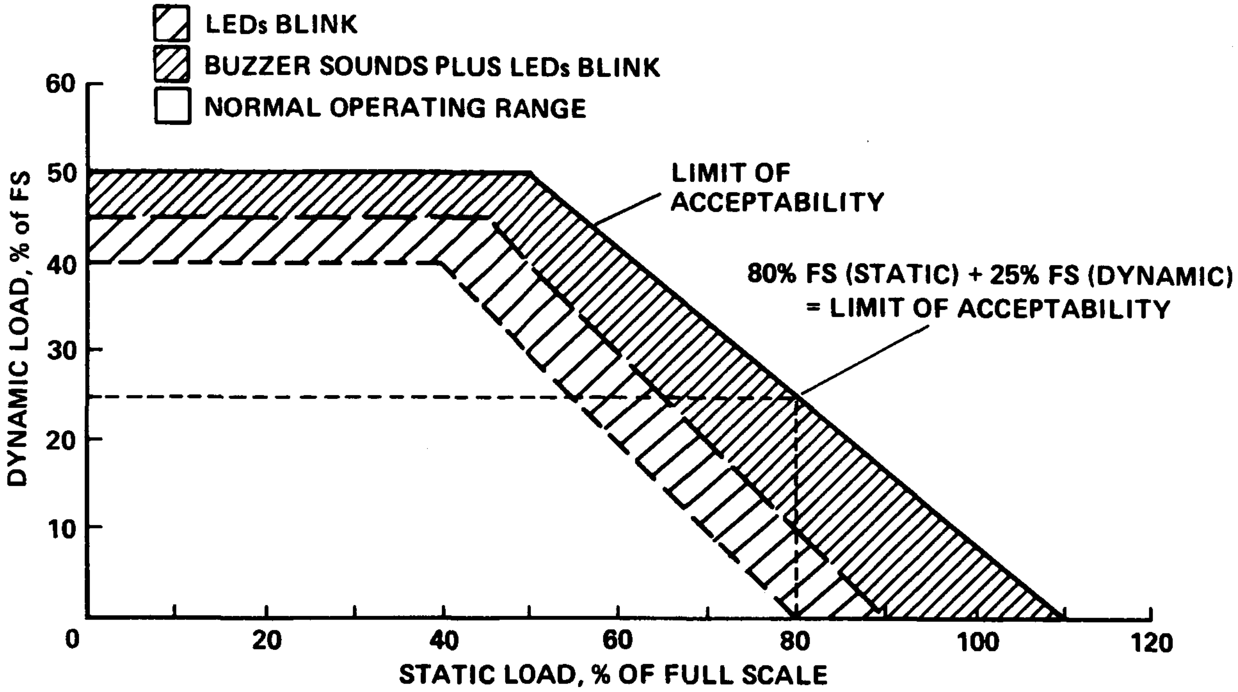

Figure 3 – Maximum Allowable Load and Alarm Algorithm.

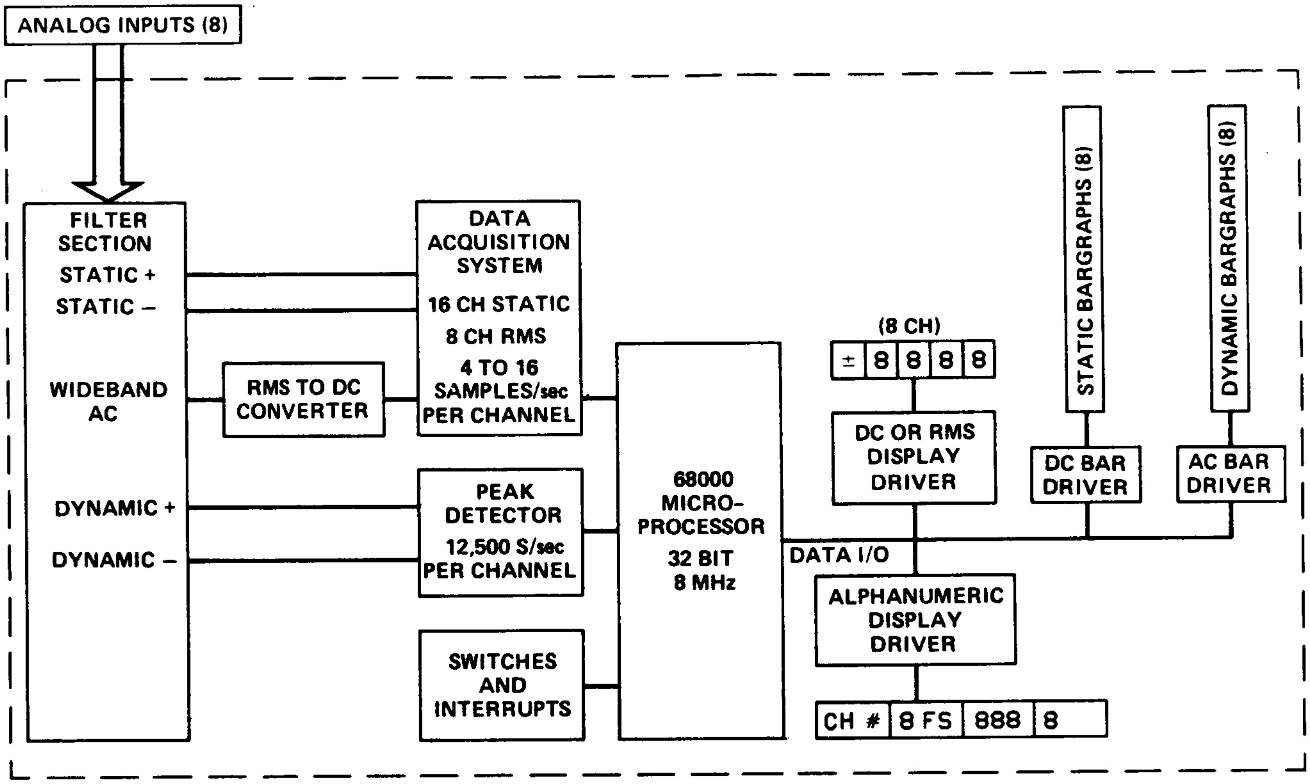

Figure 4 – BLAMS Block Diagram.

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Report Documentation Page

1. Report No. NASA TM-89455	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Visual Display and Alarm System for Wind Tunnel Static and Dynamic Loads	5. Report Date April 1987
	6. Performing Organization Code
7. Author(s) Richard D. Hanly and James T. Fogarty	8. Performing Organization Report No. A-87105
	10. Work Unit No. 505-61-91
9. Performing Organization Name and Address Ames Research Center Moffett Field, CA 94035	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code

15. Supplementary Notes

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Moffett Field, CA 94035 (415) 694-6262 or FTS 464-6262

16. Abstract

A wind tunnel balance monitor and alarm system developed at NASA Ames Research Center will produce several beneficial results. The costs of wind tunnel delays because of inadvertent balance damage and the costs of balance repair or replacement can be greatly reduced or eliminated with better real-time information on the balance static and dynamic loading. The wind tunnel itself will have enhanced utility with the elimination of overly cautious limits on test conditions.

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17. Key Words (Suggested by Author(s)) Wind tunnel balance Balance loads monitor Bargraphs Balance alarm system	18. Distribution Statement Unclassified-Unlimited Subject Category - 09

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 10	22. Price A02

NASA FORM 1626 OCT 86

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