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EVALUATION OF THE NASA ELECTRONIC STRAIN-LEVEL COUNTER AS A FATIGUE DAMAGE MONITOR

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TECHNOLOGY INCORPORATED

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FOREWORD

Technology Incorporated, Dayton, Ohio, prepared this report to document the evaluation of the NASA Electronic Strain-Level Counter by analyzing and comparing the strain data recorded on the counter and a digital magnetic tape recorder while both were installed on an A-37B aircraft. In addition, damages were computed to determine the suitability of the strain-level counter as a fleet damage monitoring device.

Authorized under Contract F33615-72-C-1249, Project No. 1467, these services were sponsored and monitored by the Air Force Flight Dynamics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. Mr. Robert Bader (AFFDL/FBR) was the Air Force project engineer. Mr. Larry E. Clay was the Technology Incorporated project engineer.

The authors gratefully acknowledge the support of Mr. Edward P. Phillips of the NASA Langley Research Center who supplied the strain-level counter and of their company associates, especially Messrs. Cyril G. Peckham, Ronald I. Rockafellow, and Robert C. Klan.

This report was released by the authors in January, 1973. This technical report has been reviewed and is approved.

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ABSTRACT

The NASA Electronic Strain-Level Counter was evaluated by analyzing the data recorded during 26 flights on an A-37B aircraft. The strain-level counter output was compared with data from a collocated strain gage recorded by a digital magnetic tape recorder. Fatigue damages were computed for several hypothetical strain-level counters to determine their suitability as fleet damage monitoring devices. Results indicated that the NASA strain-level counter performed according to its specifications but that the fatigue damages derived from the strain-level counter data did not agree with the fatigue damages derived from the strain time history data because of the inaccuracies associated with the conversion of level crossings to cycles. Increasing the number of strain levels of the hypothetical strain-level counters did not appreciably affect the damage results. However, a hypothetical variation of the strain-level counter, termed a "strain-cycle counter," did compute damages which duplicated those derived from the strain time history within acceptable limits. To determine its potential, a strain-cycle counter device should be designed, fabricated, and tested.

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1. INTRODUCTION

Variations in the environment and operation of military aircraft flying a single basic mission cause a corresponding variation in the rate of fatigue damage during such flights and thus in the safe service life of these aircraft. For this reason, the Air Force has been exploring the potential of devices which can record strain on every aircraft in the fleet. This study was directed toward an evaluation of one such device, the NASA Electronic Strain-Level Counter, while installed on an Air Force A-37B aircraft.

Since the instrumented aircraft was participating in an operational recording program when the NASA strain-level counter was installed, strain data was recorded independently on two recording systems. This data was stored until the initiation of the current program, and then processed to evaluate the NASA Strain-Level Counter operation.

The specific objectives of this program were to:

a) determine whether the NASA Electronic Strain-Level Counter counted all crossings of the proper strain levels according to the design,
b) determine if the counter data is adequate to permit fatigue damage estimates, and
c) determine the effect of increasing the number of strain counter levels on estimated fatigue damage accuracy.

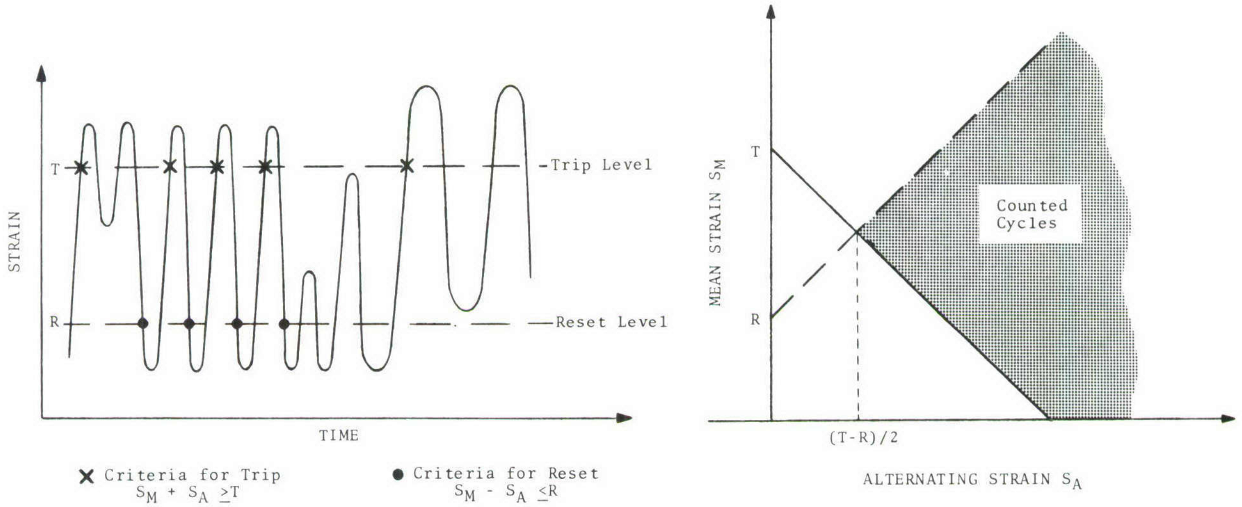
The following sections describe the recording equipment, the data collection, and the data reduction and analysis, and present the results.

2. INSTRUMENTATION

This section describes the NASA Electronic Strain-Level Counter, the A-37B Multichannel Operational Data Acquisition Program (MODAP) recording system, with its Conrac DICOR recorder and the electrical strain gage bridge installation.

2.1 NASA Electronic Strain-Level Counter

This device, referred to hereafter as the "NASA Strain Counter," is described in Reference 1. The NASA Strain Counter counts the number of times the output of a strain gage bridge exceeds each of four preset levels. A hysteresis dead band is provided at each level so that, following each exceedance of a trip level which registers a count, the strain must fall below a reset level before another count can be registered at that level. Figure 1a illustrates the operation of this device when fed by an analog signal.

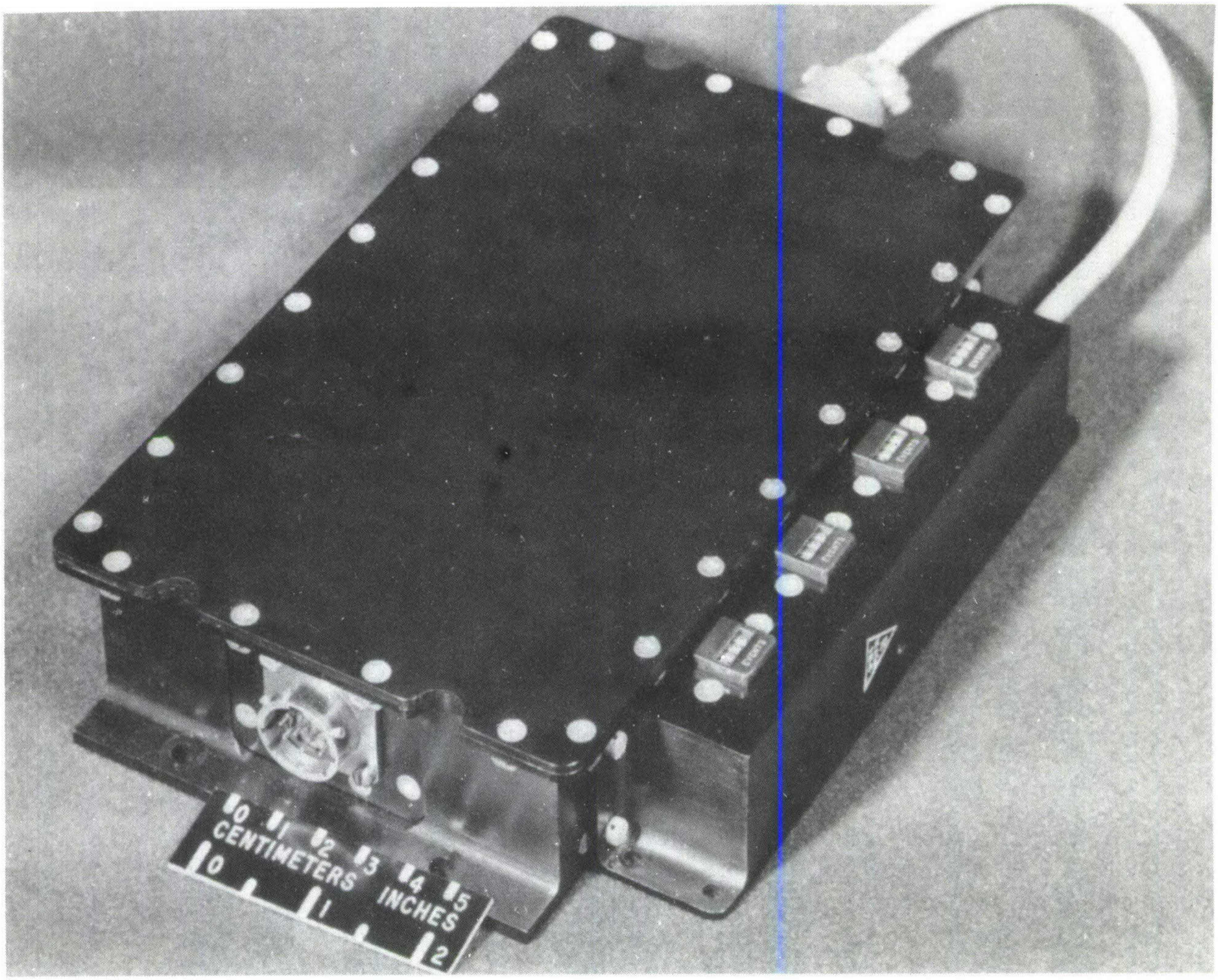


a. Illustration of Counter Operation

Figure 1. Operational Diagram and Photograph of NASA Strain-Level Counter

As shown in Figure 1b, the packaged device has a signal conditioner unit which measures 8.2 by 4.8 by 1.7 inches, a separate removable counter unit which measures 1.2 by 1.4 by 6.4 inches, and a remotely mounted strain gage. The system weight, not counting wiring, is 2.5 pounds. Each of the electromechanical counters, used for data storage and manual readout, can accumulate up to 9999 counts.

To reduce drift problems in the amplifier circuits, an ac bridge excitation provides excitation voltage pulses at a frequency of 90 hertz and a pulse duration of 0.5 millisecond.



b. Photograph of Assembled Unit

Figure 1 - Concluded

The counter circuits were designed to provide three positive trip levels and one negative trip level. The trip and reset levels for each of the four counters are adjustable and were set as listed in Table I. The bridge output was balanced (set equal to zero) after installation in the aircraft in a fully fueled configuration with no external stores. The strain polarity was set to provide positive output for compressive strains.

2.2 DICOR Recording System

The DICOR is an airborne digital magnetic tape recorder designed to continuously digitize and record 240 samples per second. Its major components are (1) a multiplexer, (2) an analog-to-digital converter, (3) a calibration circuit, (4) a tape magazine, and (5) a power supply. With its mounting plate, its dimensions are 9 by 9-3/4 by 11-1/4 inches. The DICOR tape capacity is 15 hours of data.

TABLE I. NOMINAL TRIP AND RESET STRAIN LEVELS FOR THE NASA STRAIN-LEVEL COUNTER ON THE A-37B AIRCRAFT

a) Laboratory Setup

Counters	Trip Strain (μ in./in.)	Reset Strain (μ in./in.)
Negative (Tension)	-200 (1)	-100 (1)
Low (Compression)	700	550
Medium (Compression)	1000	750
High (Compression)	1300	850

b) Field Check of Trip Values After Installation

Counters	Static Takeoff Condition-Full Fuel Tanks	Static Landing Condition-Empty Tip Tanks, Partial Main Tanks
Negative (Tension)	-240 (2)	-679 (2)
Low (Compression)	625	198
Medium (Compression)	935	512
High (Compression)	1233	816

(1) Measured change in strain from zero.

(2) Measured change in strain from actual static strain value.

With the sampling of each channel, determined by the multiplexer, the analog signal is filtered and fed to an analog-to-digital converter which transforms the analog signal amplitude to a 7-bit data word. Then a parity bit is added to the data word, and the data word is recorded on the magnetic tape.

Each time the power is turned on, the recorder generates a calibration sequence on each channel consisting of 0.6-second-duration signals at 10, 50, and 90 percent of the full-scale voltage (5 volts). The 0.6-second duration ensures that at least two samples at each level are recorded on each channel.

The data recorded on the magnetic tape in the DICOR recording system is not compatible with a digital computer. Consequently, the original data must be transcribed onto a computer tape. A tape-to-tape converter was used to perform this operation.

For the DICOR system, the signal conditioning unit consisted of (1) a system checkout circuit containing a channel selector switch and a voltmeter, (2) a regulated power source to calibrate the servo accelerometers, (3) a frequency-to-voltage converter circuit, (4) a timing circuit, (5) switching circuits for the multiplexed channels, and (6) a remote circuit to turn off the recorder when the engines shut down. The packaged signal conditioning unit measures 5 by 6-1/4 by 5 inches and weighs about 2 pounds.

2.3 Installation and Location of Electrical Strain Gages

On some of the instrumented aircraft, the recording system was designed to record electrical strains on two of the channels. The gages were arranged in two active-leg bridge circuits. The active gages of one bridge were mounted on the exposed upper forward spar cap at Left Wing Station 54.3 as shown in Figure 2 with the inactive gages located nearby for temperature compensation. The gages of the second bridge were mounted at the same location on the right wing. Amplifier circuits were installed in the signal conditioning units to increase the bridge output signals to the 5-volt full-scale level required for input to the DICOR recorder. The full-scale output was set to record a strain range of approximately 1950 μin./in. for a resolution of 15.2 μin./in. per unit change in the 7-bit digital output.

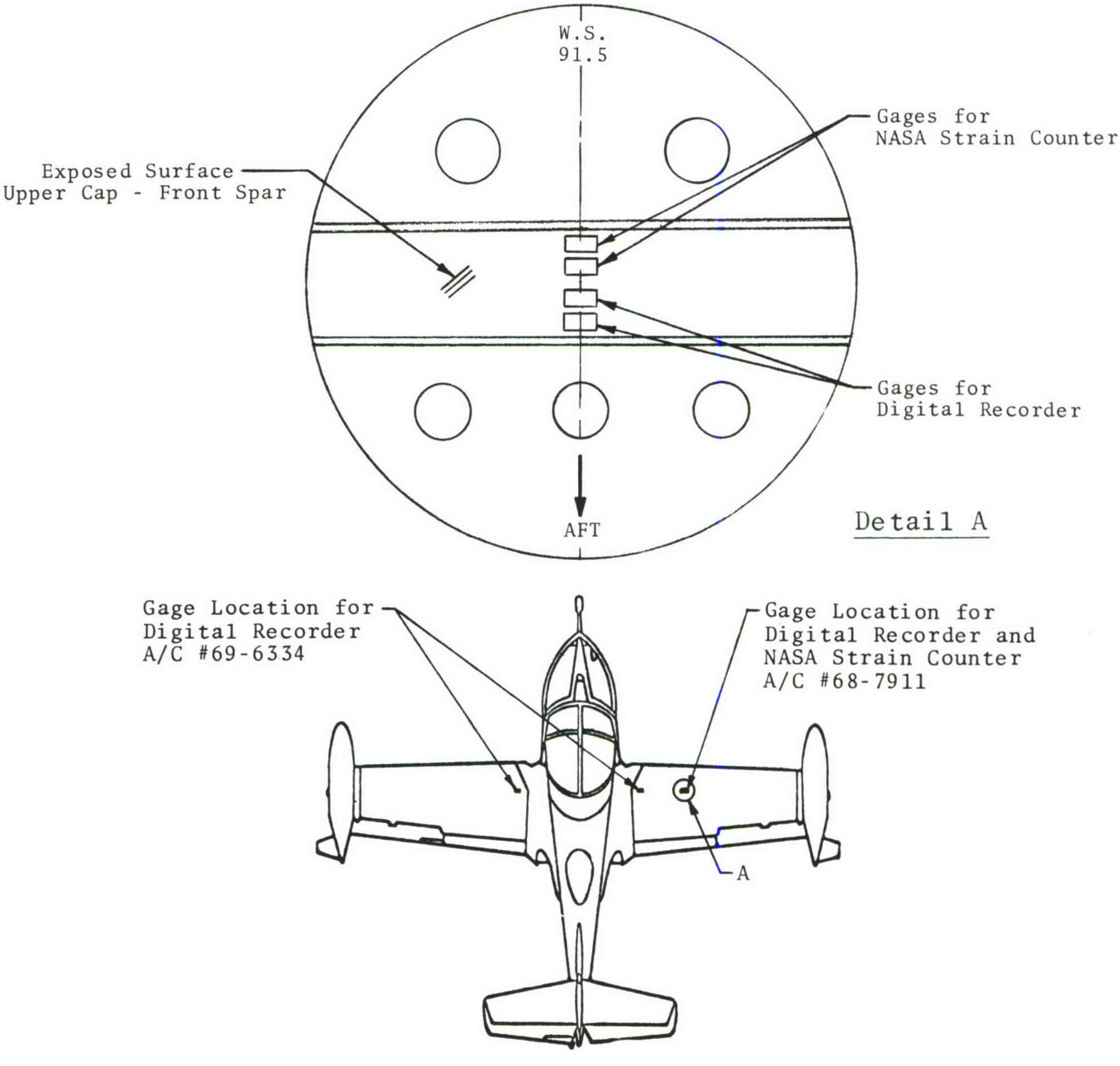


Figure 2. Location of Active Strain Gages on A-37B Aircraft

For the single A-37B aircraft (Serial No. 68-7911) with the NASA Strain Counter, one of the strain gage bridges was located side-by-side with the NASA Strain Counter gages on the upper spar cap at Right Wing Station 91.5 as shown in Figure 2, detail A. The full-scale output was set to record a strain range of approximately 3100 μin./in. for a resolution of 24.1 μin./in. per unit change in the 7-bit digital output. Four of the other channels of the DICOR recorder in this aircraft were each wired to record a pulse every time one of the four counters of the NASA Strain Counter registered a count. Thus the DICOR recorder monitored the counting operation of the NASA Strain Counter and recorded a time history of the strain adjacent to the gage which was driving the counters.

3. DATA COLLECTION

As described in Reference 2, Technology Incorporated conducted a flight data collection program on A-37B aircraft during training operations at England Air Force Base, Louisiana, and combat operations at Bien Hoa and Binh Thuy Air Bases in South Vietnam. During this program, a NASA Strain Counter was installed on one of the instrumented aircraft at England AFB, and the recording system was modified as described above to record data for use in evaluating the NASA Strain Counter.

Table II lists the two aircraft used for the current strain data study, the aircraft bases and recording periods, and the number of valid flights and valid data hours. For convenience and accessibility, an aircraft at England AFB was chosen for the strain counter study. A second aircraft at Binh Thuy was also chosen for this study to show strain data during a different type of operation. This particular aircraft was chosen because it had recorded the largest amount of usable strain data during the previous program.

TABLE II. SUMMARY OF APPLICABLE RECORDED A-37B STRAIN DATA

Aircraft Serial Number	Base	Calendar Period	No. of Magazines with Usable Strain Data	No. of Flts. with Usable Strain Data	Total Usable Hours
68-7911	England	21 Jan to 15 Mar, 1971	7	26	37.45 (1)
69-6334	Binh Thuy	17 Mar to 25 July, 1971	7	35	39.45 (2)

(1) Indicate flight data only.

(2) Indicate ground data only.

The aircraft at England AFB flew training missions and carried practice bombs and rockets or no stores at all with low gross takeoff weights (11,250-11,650 pounds). The aircraft at Binh Thuy flew combat missions and carried heavy bombs accounting for higher gross takeoff weights (13,000 pounds). Because of this difference in mission type and configuration, the strain data recorded during England AFB flight operations and during Binh Thuy AB ground operations were selected for use in this study.

Contractor technicians installed and maintained the electrical strain gage recording systems, obtained supplemental information, and shipped the data to the data processing facility in Dayton, Ohio. For each flight, the supplemental information included date; takeoff and landing times, weights, configuration, base, and runway surface; mission type; aircraft serial number; squadron; wing; and the strain counts for the NASA Strain Counter data.

4. DATA REDUCTION

The recorded data was processed to extract cycles and level crossings from the electrical strain data and the strain values corresponding to the recorded trip of each level of the NASA strain counter.

A series of existing and new computer programs were employed in the data reduction. One program listed three selected channels of data in plotted form and stored them on a "plot tape." From these listings, a data analyst identified the preflight taxi and takeoff, flight, and the landing and post-flight taxi segments. A preprocessing computer program extracted all peaks and troughs (separated by at least a 70 μin./in. threshold) from the strain data, and listed and stored them in chronological order on tape. Then this tape was processed through a strain cycle program which processed the peaks and troughs into cycles and listed them in a separate table for each mission segment. A level crossing program extracted from the digital strain time history on the "plot tape" the level crossings corresponding to four hypothetical strain counters. Another program--the trip/reset--also scanned the recorded tape and extracted the strain value coincident with each recorded trip of the NASA strain counter levels and the minimum strain value reached between successive trips for the deduction of actual trip and reset levels for the NASA strain counter.

Fatigue damage calculations were performed manually from the output of the strain cycle and the level crossing programs. The following paragraphs briefly describe the definitions used during the data reduction.

4.1 Level Crossing Program Description

This program was designed to simulate strain counters having 4 levels, 8 levels, 12 levels, and 16 levels. Table III lists the strain values for the trip and reset of each level of the counters. Table III,a contains the levels used in processing the A-37B data recorded at England Air Force Base, Louisiana, and Table III,b contains the levels used in processing A-37B data recorded at Binh Thuy Air Base, South Vietnam. The input to this program included a tape containing a digital time history of strain and cards defining the trip and reset strain values for each level of the four hypothetical strain counters. The output was a table of the number of occurrences in each level of the four counters for each flight.

4.2 Trip/Reset Program Description

The trip/reset program was designed to scan a tape of recorded strain data containing pulses on DICOR recorder channels 14, 15, 16, and 20 corresponding to trips of the low, negative, high, and medium levels, respectively, of the NASA strain counter. The strain value coincident with each recorded pulse

TABLE III. NOMINAL TRIP AND RESET STRAIN LEVELS FOR FOUR HYPOTHETICAL STRAIN-LEVEL COUNTERS

a) For A-37B Upper Wing Spar - England AFB (Polarity reversed so that positive strains are compressive to match NASA counter data)

Strain Levels (μ in./in.)

Counter No.	4-Level Counter		8-Level Counter		12-Level Counter		16-Level Counter	
	Trip	Reset	Trip	Reset	Trip	Reset	Trip	Reset
1	-200	-100	-300	-200	-300	-200	-400	-200
2	700	550	-200	-100	-200	-100	-300	-200
3	1000	750	400	200	300	100	-200	-100
4	1300	850	600	400	400	200	200	100
5			800	650	600	400	300	100
6			1000	750	700	550	400	200
7			1200	800	900	700	500	300
8			1400	850	1000	750	600	400
9					1100	750	700	550
10					1200	800	800	650
11					1300	850	900	700
12					1400	850	1000	750
13							1100	750
14							1200	800
15							1300	850
16							1400	850

b) For A-37B Upper Wing Spar - Binh Thuy AB

Strain Levels (μ in./in.)

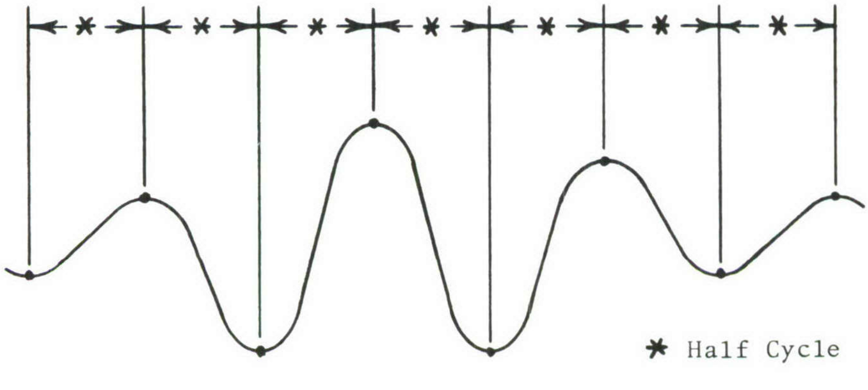
Counter No.	4-Level Counter		8-Level Counter		12-Level Counter		16-Level Counter	
	Trip	Reset	Trip	Reset	Trip	Reset	Trip	Reset
1	-200	-100	-400	-300	-400	-300	-400	-300
2	200	100	-200	-100	-200	-100	-300	-200
3	700	500	200	100	200	100	-200	-100
4	1000	750	400	300	300	200	-100	0
5			600	450	400	300	100	0
6			800	600	500	400	200	100
7			1000	750	600	450	300	200
8			1400	900	700	500	400	300
9					800	600	500	400
10					900	700	600	450
11					1000	750	700	500
12					1400	900	800	600
13							900	700
14							1000	750
15							1200	900
16							1400	900

(or trip) was extracted and stored with the minimum strain value following the trip and preceding the next recorded trip. The output is a set of four tables for each flight, each presenting the number of occurrences of the combinations of trip and reset values for each of the four levels.

4.3 Strain Cycle Computer Program

Based on the method from Reference 3, a computer program to extract cycles from a sequence of strain peaks and troughs was utilized for processing the electrical gage strain data. This program uses a modified range-pair technique of grouping peaks and troughs into cycles. The technique starts with the smaller cycles and extracts from the time history each peak-trough pair which is bounded by a larger peak-trough pair. This process is continued until none of the remaining peaks and troughs are bounded by a larger peak-trough pair. Then the remaining peaks and troughs, or residue, are considered to be a sequence of half cycles with each peak or trough shared by the preceding and following point. The technique is illustrated in Figure 3.

a) Extraction of Cycles from a Larger Cycle



b) Pairing the Residue into Half-cycles

Figure 3. Modified Range-Pair Technique for Pairing Peaks and Troughs into Cycles (Reference 3)

For each cycle and half cycle, the computer program assigns a mean strain SM equal to the average of the peak and trough values and an alternating strain SA equal to half the difference between the peak and trough values. To provide an integer output, the program counts each half cycle as one (1) and each cycle as two (2). The output is a table with half cycle counts in corresponding intervals of SA and SM.

4.4 Fatigue Damage Calculations

In computing fatigue damage, Miner's rule of cumulative damage was used to combine the damages at the various load levels. The allowable SN data for 7075-T6 aluminum with a stress concentration factor K_t of 5.0 was taken from the literature to provide consistent and realistic damage computation results.

The strain gage locations on the instrumented A-37B aircraft were selected on the upper wing surface to monitor ground loads. The counts for the hypothetical counters and the cycles for the electrical gage data were derived for the two sets of A-37B data and then the counter trip strain levels and the cycle strain amplitudes were modified and converted to stresses by using one of two hypothetical transfer functions.

The data recorded at England Air Force Base, with lightweight training armament, indicated that the wing strains during ground operation were relatively low and were not representative of damage computations. Therefore, for this data, a hypothetical transfer function was devised to transfer the recorded strains on the upper spar cap at Wing Station 91.5 to stresses in the lower spar cap at Wing Station 9.15 as follows:

$$\sigma_{91.5L} = 1.46E\varepsilon_{91.5U} - 5250$$

where

$\sigma_{91.5L}$ = stress at lower wing station 9.15 in psi.
$\varepsilon_{91.5U}$ = strain at upper wing station 9.15 in in./in.
E = modulus of elasticity = 10.3×10^6 psi.

and the upper wing strains were arbitrarily set equal to zero under static ground load in the fully fueled condition with no stores.

To demonstrate the use of the strain counter for recording ground-sensitive loads, the recorded strains on the upper spar cap at Wing Station 54.3 of the A-37B engaged in combat operations at Binh Thuy Air Base were increased by a hypothetical transfer function to produce amplified stresses at Wing Station 54.3 as follows:

$$\sigma_{54.3U}^{*} = 2.0E\varepsilon_{54.3U} + 5000$$

where

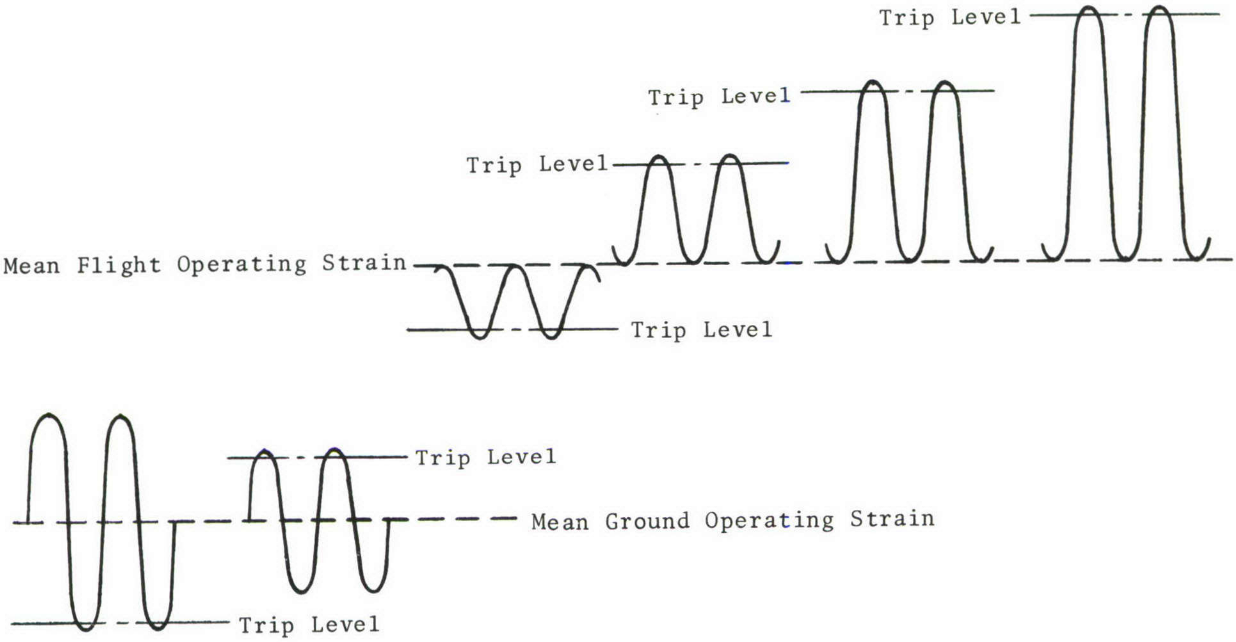
$\sigma_{54.3U^*}$ = amplified stress at upper wing station 54.3 in psi.
$\varepsilon_{54.3U}$ = strain at upper wing station 54.3 in in./in.
E = modulus of elasticity = 10.3×10^6 psi.

and, again, the upper wing strains were arbitrarily set equal to zero under static ground load in the fully fueled condition with no stores.

The electrical strain gage data half cycles were assigned mean and alternating strain values equal to the midpoint of the tabulated intervals, and the damage for each half cycle was assumed equal to half the damage for a cycle. The damage was evaluated for each mission segment: preflight ground, flight, and post-flight ground. A ground-air-ground (GAG) cycle was assumed with a trough equal to the mean of the preflight ground data and a peak equal to the maximum flight value.

The strain counter data required additional assumptions before the damage could be computed because the level crossing information had to be converted to strain cycles. To permit this conversion, two techniques were used: 1) a classical range-pair method which pairs the highest level crossing with the lowest level crossing until the counts in the respective levels or the intermediate levels are exhausted, and 2) an alternate method based on the assumptions listed and illustrated in Figure 4. Since the counter data cannot be obtained for mission segments, the data was processed as individual flights.

The use of the conceptual cycle shapes shown in Figure 4 requires estimation of the flight and ground mean values and the determination of the number of cycles at each mean and alternating strain level. To determine the number of cycles, the number of crossings at each level was reduced by the number of cycles at all higher levels which also cross this level. Whenever this technique computed a negative number of cycles for a level, the number was set equal to zero. The number of counts at each positive level was reduced by one to extract the GAG cycle. A flight mean strain value was computed by averaging the values of all level crossings at or above the positive level with the highest count. A ground mean was computed by averaging the level crossings if the number of levels permitted symmetrical placement about the nominal ground mean. Otherwise, the ground mean value was assumed equal to the nominal ground mean. Then the mean and alternating stresses were computed for the counts recorded in each level, and the damage per cycle was extracted from the SN data and multiplied by the number of counts. The GAG cycle was defined for the strain counter data in the same way as for the electrical strain data.



Assumptions:

1. All strain cycles during ground operation are symmetrical about the ground mean.
2. All strain cycles during flight operation which cross a level below the flight mean have peaks equal to the flight mean.
3. All strain cycles during flight operation which cross a level above the flight mean have troughs equal to the flight mean.

Figure 4. Illustration of Alternate Cycle Formation for Strain-Level Counter Data Damage Calculations

5. ANALYSIS

5.1 Evaluation of NASA Strain Counter Trip/Reset Levels

The output of the trip/reset computer program indicated a variation in the recorded electrical strain gage output at the time of the trip and reset of each level of the NASA Strain Counter. Some of this variation was caused by the resolution of the digital recorder of 1/127 of full scale or about 24 μin./in. Another cause of variation was the sampling rate of the different recorder channels which was designed so that the strain value could change significantly between the actual trip and the time of the recorded sample which responded to the trip. Because of this uncertainty in the strain corresponding to the trip, the recorded data is presented in cumulative frequency plots in Figure 5. The mean value of the electrical strain gage output for each level and the standard deviation of the distribution were computed and compared with the laboratory setup and field check values for the NASA Strain Counter in Table IV.

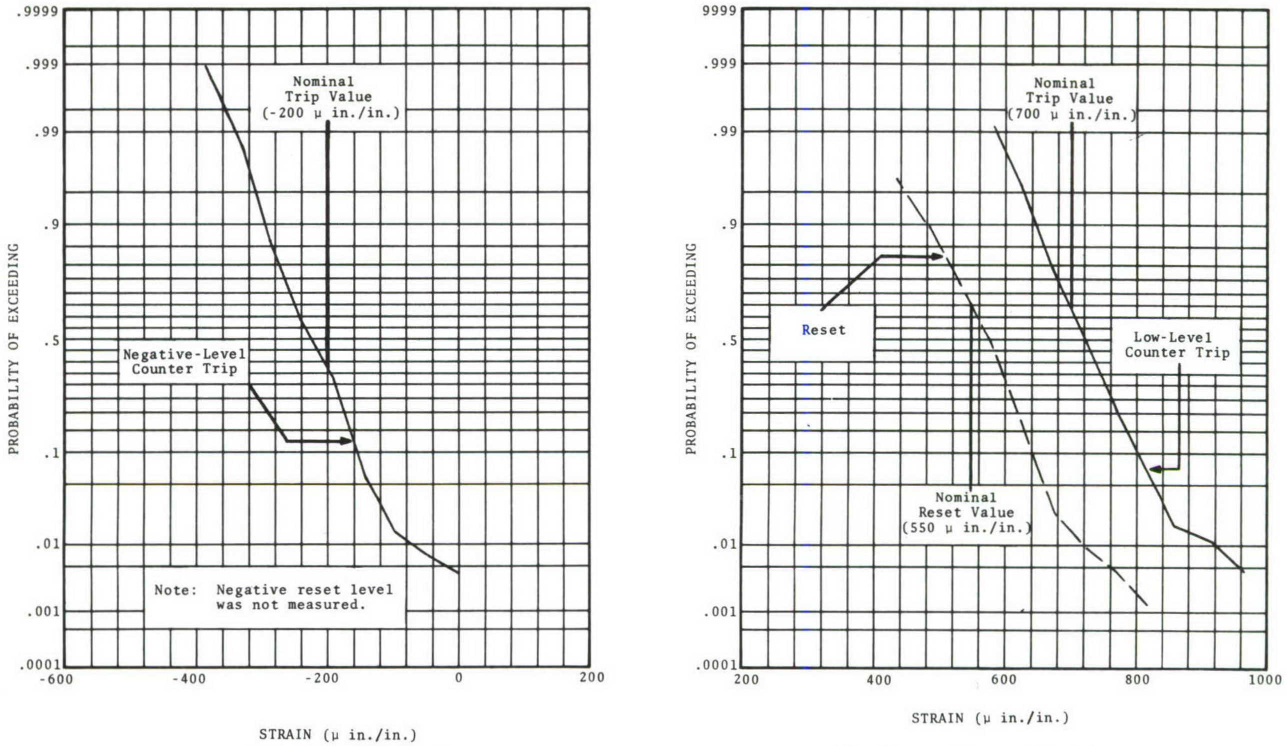
TABLE IV. COMPARISON OF ELECTRICAL GAGE OUTPUT AT NASA STRAIN-LEVEL COUNTER TRIP AND RESET WITH NOMINAL LABORATORY AND FIELD TEST SETUP VALUES

Strain (μin./in.)

		NASA Strain Counter		Electrical Gage Data		
Counter	Function	Lab Setup	Field Check*	No. of Occurrences	Mean	Std. Deviation
Negative	Trip	-200	-240	1560	-225	61.7
	Reset	-100	-	1554	**	**
Low	Trip	700	625	2511	725	64.1
	Reset	550	-	2511	569	67.0
Medium	Trip	1000	935	141	1108	93.7
	Reset	750	-	139	740	124.3
High	Trip	1300	1233	33	1440	56.4
	Reset	850	-	35	840	76.4

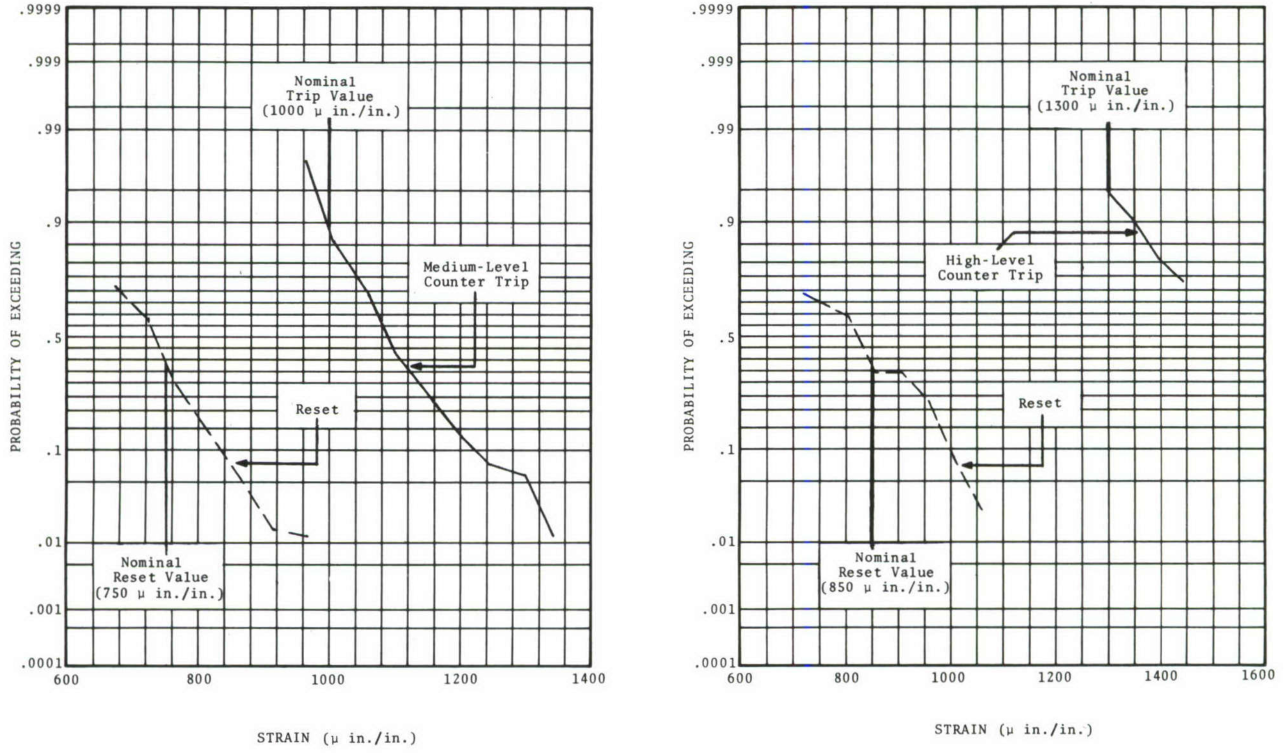
* Measured during installation. Reset values were not measured.

** Could not be deduced because of its proximity to the preflight taxi mean strain (0.0 μin./in.).



a) Negative-Level Counter

b) Low-Level Counter



c) Medium-Level Counter

d) High-Level Counter

Figure 5. Probability of Exceeding an Electrical Gage Output Strain Level at the Time of the NASA Strain-Level Counter Trip and Reset

For the Negative and Low counters, the recorded trip and reset levels match the laboratory setup values very closely; however, for the Medium and High counters, the trip levels are more than 100 μin./in. higher than the laboratory setup values even though the reset values are again in agreement. This difference in the average trip strain values resulted from the technique used to detect the time of the trip as described above. This technique introduced a lag in the measurement of the trip strain; consequently, since the strain was increasing during the lag, the value digitized at the end of the lag was too high. Therefore, it is suspected that the average trip strains were actually nearer the nominal values than the data results indicate.

5.2 Evaluation of NASA Strain Counter Frequencies

The number of counts recorded by each level of the NASA Strain Counter was compared with the hypothetical four-level strain counter applied to the DICOR electrical strain gage data. Preliminary results appeared to be poorer than expected. However, further examination of the hypothetical strain counter data revealed a large difference in counter output when the trip level was altered by a single bit (1/127 of full scale). To provide the best approximation of the NASA Strain Counter, the hypothetical four-level counter was revised to the mean trip/reset levels found in Section 5.1, and the DICOR data was reprocessed. The results of this four-level counter were compared with the NASA Strain Counter data on a flight-by-flight basis in Figure 6 and in Table V. The NASA Strain Counter output for six flights is not shown because it was omitted or erroneously recorded on the manual entry form. On the flights indicated by solid triangle symbols in Figure 6, malfunction of the digital recorder during a portion of the flight caused the count of the hypothetical strain counter to be too low.

In general, there is agreement between the number of level crossings obtained from the strain gage counter and from the recorded electrical strain with the differences no greater than those associated with altering the level values by the minimum change. This minimum change is 1 bit and is equivalent to 24 μin./in. Although one flight, No. 17, had a much lower number of occurrences in the data derived from the electrical strain gage than that recorded in the NASA Strain Counter low level, a premature shutdown of the DICOR recorder may have caused the lower number of occurrences.

One result of this study was to illustrate the sensitivity of the recorded counts to the choice of trip/reset levels. It was noted that the Negative level was a little below the preflight mean strain value and recorded few counts during some flights and many counts on other flights. The Low level was chosen very near the in-flight mean strain value and recorded about 100 counts on most flights. The Medium and High levels were above the in-flight mean strain and recorded only the significant maneuver strains. Because of their placement near mean operating strain values, the

Negative and Low levels were very sensitive to slight changes in the trip level due to either inherent operation or drift in the instrumentation.

TABLE V. COMPARISON OF COUNTS RECORDED BY THE NASA STRAIN-LEVEL COUNTER AND A HYPOTHETICAL FOUR-LEVEL STRAIN-LEVEL COUNTER FOR 26 A-37B FLIGHTS

	NEGATIVE		LOW		MEDIUM		HIGH	
FLIGHT NUMBER	NASA	DICOR	NASA	DICOR	NASA	DICOR	NASA	DICOR
1	36	0	4	4	2	5	1	2
2	51	11	54	34	3	4	0	0
3	54	13	74	69	11	12	2	8
4	52	25	229	226	4	13	4	6
5	31	15	44	60	7	16	1	1
6 *		1		101		6		2
7 *		0		239		34		4
8	90	27	112	126	5	6	0	0
9 *		7		200		21		10
10 *		15		345		41		12
11	51	17	85	63	11	25	0	0
12	309	393	102	24	2	3	1	2
13	297	404	106	23	5	8	1	1
14	5	0	7	9	18	26	6	8
15	33	60	183	176	7	15	1	6
16	47	108	65	54	26	21	5	0
17	158	126	200	33	4	3	0	0
18	23	62	22	9	9	9	0	0
19	31	21	103	78	4	5	0	0
20	171	188	78	132	6	16	3	4
21	173	108	201	223	5	11	0	0
22	64	0	121	92	7	11	1	0
23	30	88	101	30	9	4	0	0
24	83	52	51	101	8	5	3	0
25 *		141		75		13		0
26 *		322		102		15		7

* NASA STRAIN COUNTER DATA WAS NOT READ AFTER THESE FLIGHTS.

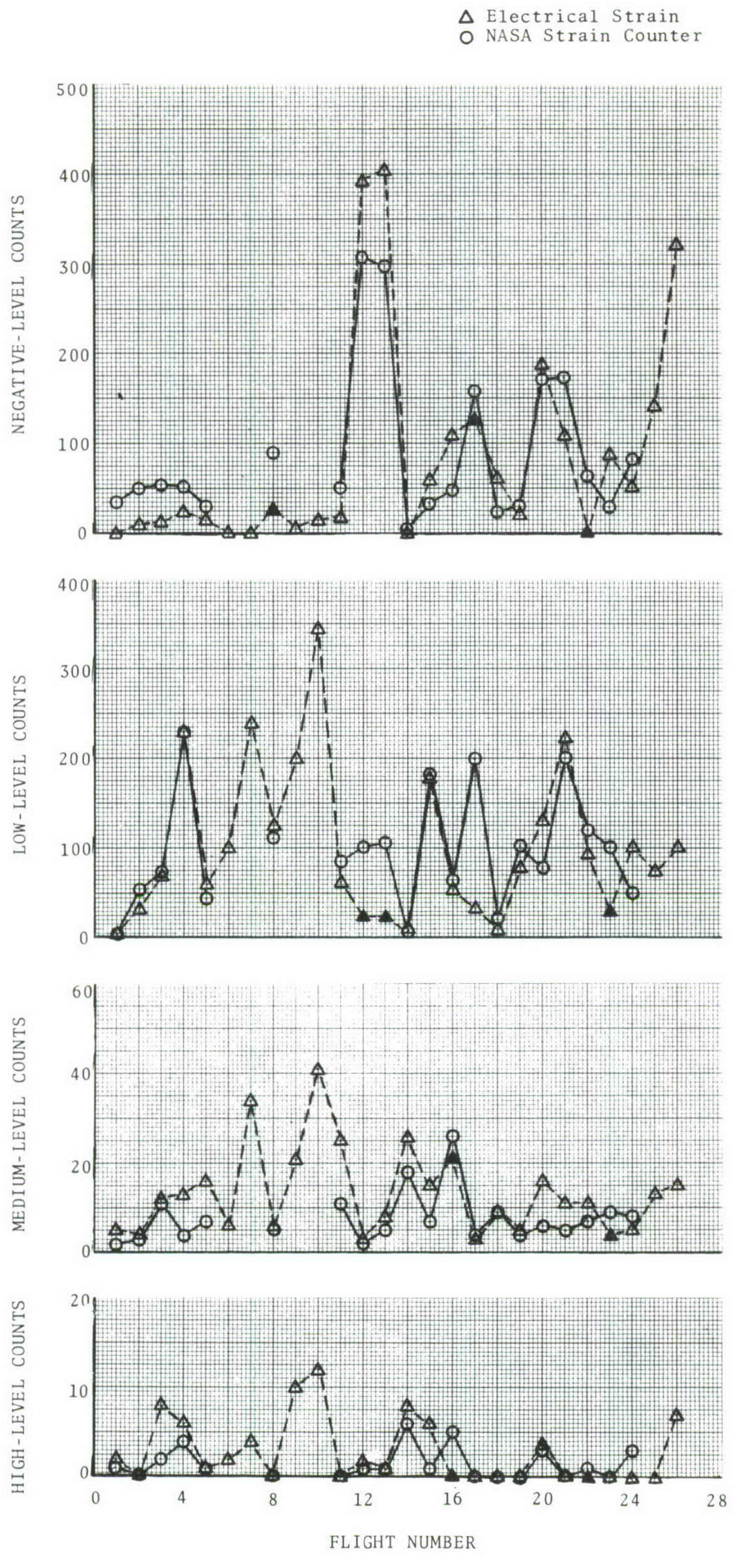


Figure 6. Comparison of NASA Strain-Level Counter Output with Similar Data Derived from an Electrical Gage Output Time History During 26 Flights by an A-37B

5.3 Fatigue Damage Versus Number of Strain Counter Levels

To study the effect of increasing the number of strain counter levels, the electrical strain gage data was processed to obtain frequencies in each level of a four-level, an eight-level, a twelve-level, and a sixteen-level strain counter. These frequencies are presented in Tables IX and X in the Appendix. The data was also processed to obtain cycles from the strain time history as described in Section 4.3. Then fatigue damage was computed for each set of data. For each flight, Table VI lists the computed damages for the A-37B lower wing surface data from England Air Force Base and for the A-37B upper wing surface data from Binh Thuy Air Base. (Note that the stresses computed for this data were artificially obtained and that the damages presented are for comparison of the data herein and do not represent the actual A-37B structure.)

TABLE VI. FATIGUE DAMAGE $n/(Nx10^{-6})$ BY FLIGHT DERIVED FROM FOUR HYPOTHETICAL STRAIN-LEVEL COUNTERS AND FROM AN ELECTRICAL GAGE OUTPUT TIME HISTORY

a) A-37B Lower Wing Spar - England AFB (Flight Data)

	RANGE-PAIR				ALTERNATE METHOD				
FLIGHT NUMBER	4-LEVEL COUNTER	8-LEVEL COUNTER	12-LEVEL COUNTER	16-LEVEL COUNTER	4-LEVEL COUNTER	8-LEVEL COUNTER	12-LEVEL COUNTER	16-LEVEL COUNTER	ELECTRICAL CYCLES
1	48.18	145.10	181.00	203.70	63.80	81.30	94.00	57.00	94.50
2	77.87	75.72	95.00	113.20	11.80	35.50	31.40	27.20	36.10
3	290.45	162.50	218.50	240.00	115.80	100.50	103.70	82.10	278.00
4	276.29	390.00	397.29	227.29	74.50	99.20	92.80	80.40	307.90
5	290.45	384.80	403.12	233.12	52.00	94.20	89.50	85.70	122.50
6	276.29	142.50	197.75	219.25	65.30	85.60	80.60	74.10	162.80
7	126.76	221.00	216.10	216.10	154.10	137.90	175.30	121.30	178.90
8	77.29	176.60	87.00	105.20	12.90	35.50	34.40	32.20	31.30
9	332.35	258.70	325.51	347.01	157.30	116.00	108.70	127.90	325.40
10	475.06	601.00	483.46	504.96	384.50	255.20	241.70	206.60	474.10
11	419.00	542.50	593.20	445.00	226.60	168.70	150.70	168.20	201.70
12	276.00	373.70	383.00	383.00	65.50	81.30	75.10	91.60	136.50
13	263.29	390.00	380.00	380.10	57.30	85.60	79.50	89.90	117.80
14	340.08	264.70	331.94	383.00	144.60	171.90	171.80	153.60	282.50
15	330.32	436.60	441.68	463.60	155.90	117.30	165.50	159.00	331.90
16	322.25	207.70	350.72	230.62	110.50	63.70	86.00	87.00	124.60
17	78.45	86.56	123.33	122.84	20.60	17.10	22.80	26.70	27.90
18	79.32	166.60	172.19	96.87	58.80	43.30	32.10	27.10	38.20
19	263.58	166.60	123.84	146.24	58.10	31.60	52.20	41.60	51.40
20	303.74	474.70	468.04	468.04	117.90	123.00	138.60	141.50	184.90
21	85.99	191.35	215.09	200.88	58.10	41.00	43.50	59.80	49.10
22	63.50	176.63	217.10	233.80	90.70	86.30	97.10	83.70	87.80
23	80.19	187.33	198.56	192.31	28.10	34.50	31.90	35.00	37.40
24	264.74	178.21	273.00	273.00	52.90	45.60	51.00	55.30	62.70
25	303.74	436.60	442.15	442.15	68.30	114.20	124.20	130.40	107.10
26	304.32	431.78	457.25	457.25	115.40	126.10	114.60	117.00	320.70

TABLE VI - Concluded

b) A-37B Upper Wing Spar - Binh Thuy AB (Ground Data)

	RANGE-PAIR				
FLIGHT NUMBER	4-LEVEL COUNTER	8-LEVEL COUNTER	12-LEVEL COUNTER	16-LEVEL COUNTER	ELECTRICAL CYCLES
1	3.57	3.82	3.82	4.37	8.16
2	7.24	15.34	20.24	21.76	3.43
3	12.10	12.10	12.48	57.47	56.88
4	1.96	2.51	4.07	6.96	4.00
5	9.55	23.71	26.98	70.17	103.76
6	7.25	22.94	23.83	60.33	41.21
7	0	.15	3.19	3.19	.05
8	0	.70	1.48	1.85	.50
9	12.16	16.24	24.97	24.97	8.93
10	.70	7.33	9.91	13.87	4.92
11	5.88	6.83	17.46	20.40	5.10
12	0	.15	.15	.39	0
13	0	.20	.98	1.99	.25
14	0	.20	.20	.62	.05
15	1.96	3.11	3.89	5.72	1.96
16	0	0	0	.05	0
17	0	0	0	0	0
18	2.15	5.72	11.99	19.57	6.12
19	3.92	5.62	12.06	14.76	6.12
20	0	.20	.20	.52	.05
21	0	0	0	.30	0
22	0	0	0	2.20	.05
23	1.96	3.21	8.67	12.56	4.39
24	0	.20	.20	.57	.10
25	7.84	7.99	10.10	14.39	2.52
26	1.96	19.40	20.18	24.15	.91
27	0	.05	.05	.23	1.11
28	0	0	0	.05	2.59
29	0	.10	.10	.18	1.57
30	0	.05	.05	.13	2.69
31	0	.20	.20	.28	0
32	0	.15	.15	.58	.05
33	.10	1.12	1.57	1.57	0
34	.95	.95	1.52	1.52	1.21
35	.25	2.80	5.77	5.87	3.97

For comparison, the damages for the strain cycles (the "electrical cycles" in Table VI) were assumed to be correct, and the damages for each of the hypothetical counters (also in Table VI) were changed to differences or errors from the "correct" value. The average and standard deviation were computed for the set of damage differences representing each of the hypothetical counters. These averages and standard deviations are plotted versus the number of counter levels in Figures 7 and 8.

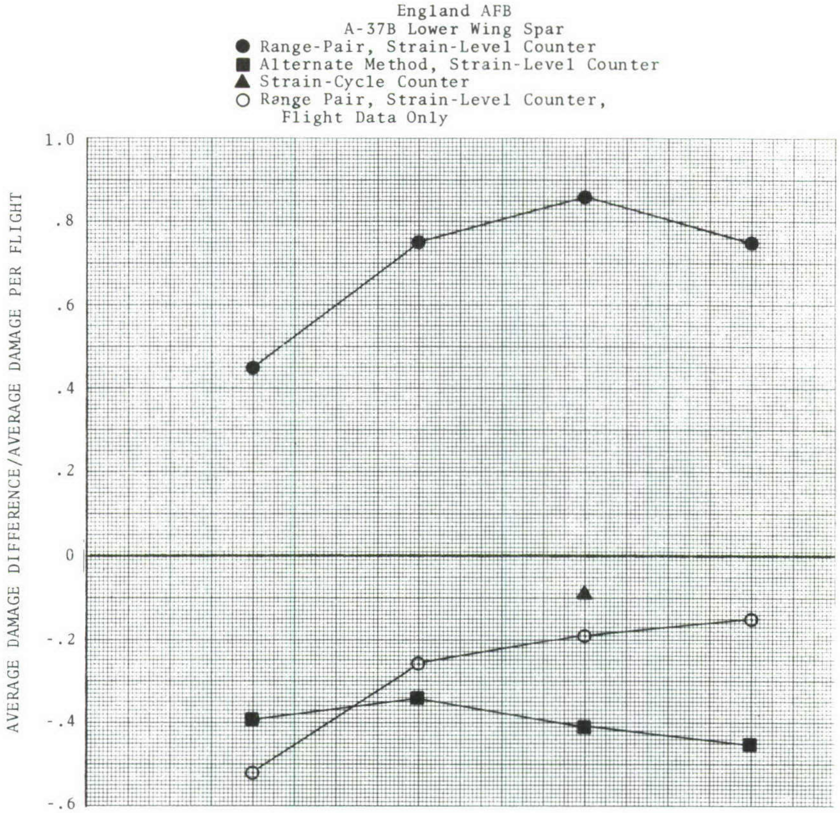
Figure 7a presents the average damage difference per flight divided by the average damage per flight for the four strain counters on the England AFB data. The average damage computed by the range-pair technique of defining the cycles was always higher and the average damage computed by the alternate method was always lower than the damage from the strain cycle data. From this figure, it appears that the number of counter levels has little effect on the accuracy of the computed fatigue damage. To determine the reason for this unexpected result, the flight data only for the range-pair technique was compared with similar data for the strain cycle data. In this case, the results were as expected, with the average differences increasing when more levels were added. Therefore, the unexpected results in Figure 7a stem from the GAG cycle damage. It was discovered that the choice of levels caused the results. The omission of the 1400 in./in. level on the four-level counter caused this data to have the lowest damages. The addition of the 200 in./in. level on the sixteen-level counter caused the preflight ground mean to be estimated at +200 on many flights when the eight-level and twelve-level counters had an estimated value of -200; consequently, the sixteen-level counter had lower computed damages.

The standard deviation of the damage differences is presented in Figure 7b. Again, there is no apparent increase in accuracy with an increase in the number of counter levels.

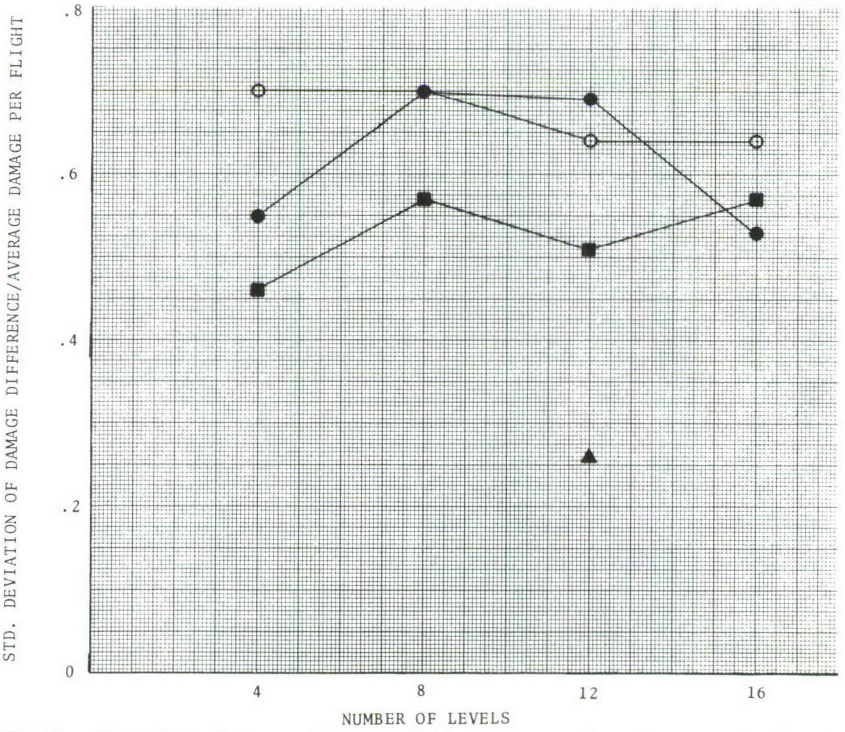
The "strain-cycle counter" data presented in Figures 7a and 7b will be discussed later.

The damage differences for the counters when applied to the ground operation data from Binh Thuy Air Base are presented in Figures 8a and 8b. Only the range-pair method of defining cycles was used to compute damage from this set of counter data. Because of a limitation in the recorded data, only the ground data for the upper wing surface was utilized, and no attempt was made to estimate the GAG cycle damage. Because of the selection of counter levels, the mean damage was low for the four-level, eight-level, and twelve-level counters but was high for the sixteen-level counter. The standard deviation of damage differences decreased as the number of levels was increased.

It was observed in both sets of data that the differences in damage were influenced more by the placement of the counter trip levels than by the number of levels. Also, since the mean strain during ground and flight operation varied from flight to



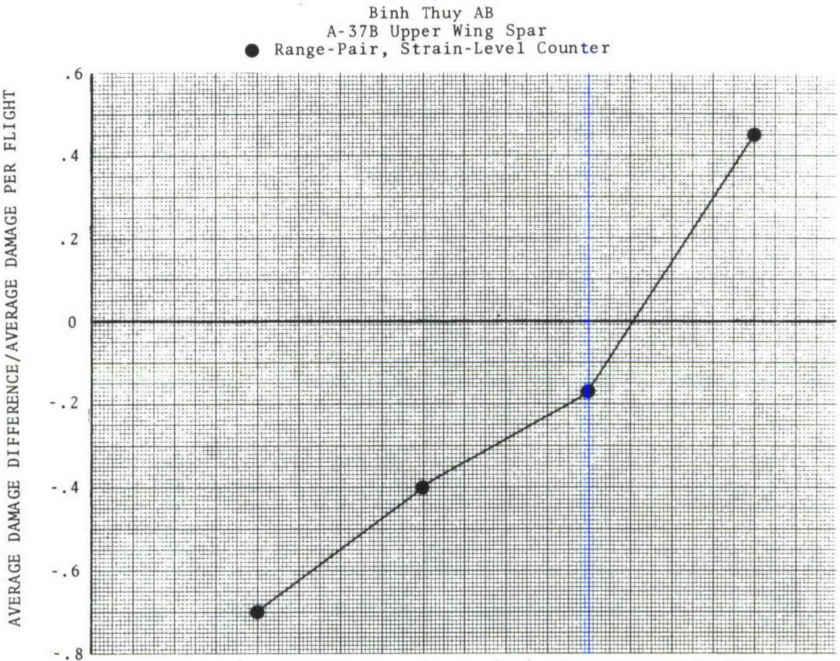
a) Average Differences in Computed Damage



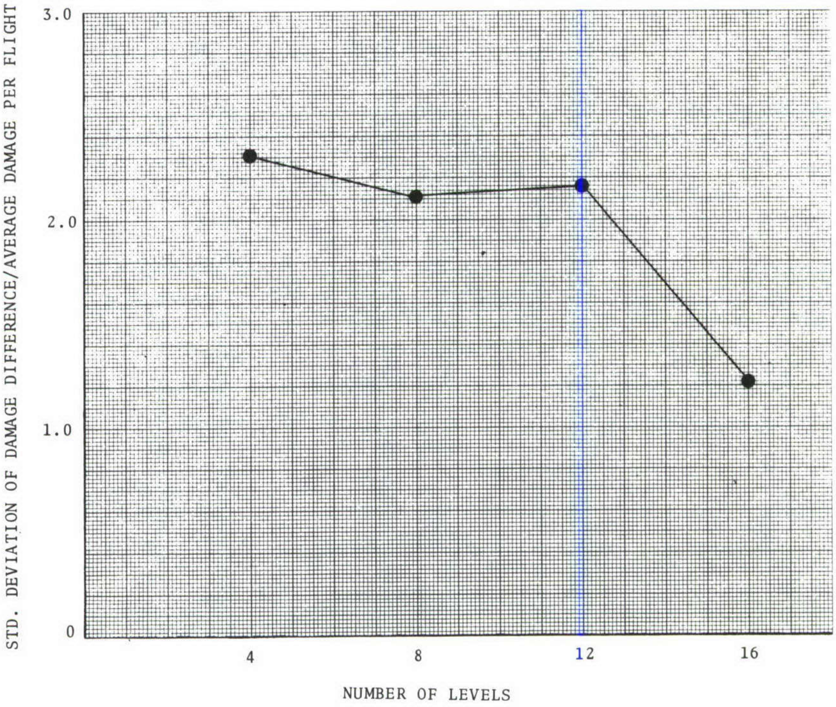
b) Std. Deviation of Differences in Computed Damage

Figure 7. Differences in Fatigue Damage Derived from Four Hypothetical Strain-Level Counters and a Hypothetical Strain-Cycle Counter on the A-37B Lower Wing Surface

flight and with weight changes within a flight, it is impossible to select a single set of levels which will always agree with results from time history recording.



a) Average Differences in Computed Damage



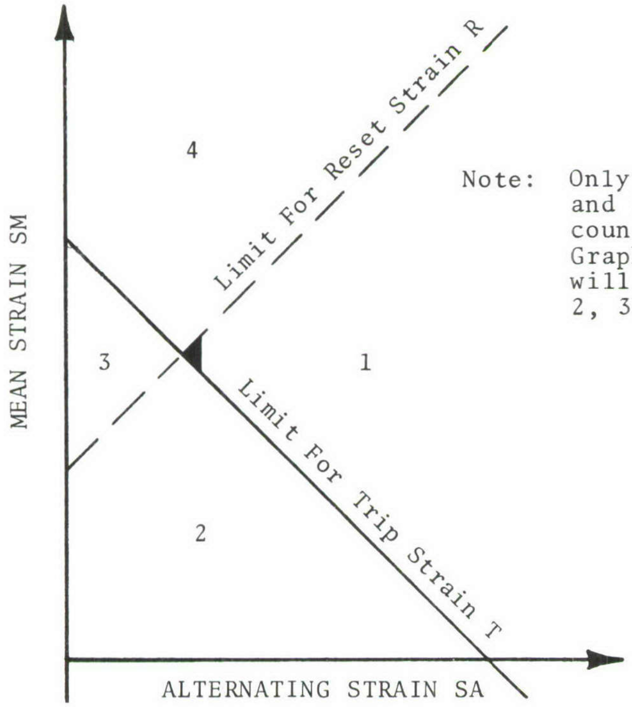
b) Std. Deviation of Differences in Computed Damage

Figure 8. Differences in Fatigue Damage Derived from Four Hypothetical Strain-Level Counters on the A-37B Upper Wing Surface

For the application considered, it appears that level crossing data cannot be used to duplicate the results of sequenced strain cycle data regardless of the number of levels available. The reason for this lack of agreement is the inability to convert the level crossing data to cycles without making gross, and sometimes erroneous, assumptions. Therefore, a strain-level crossing type of counter device would be useful for fatigue damage monitoring only if damage computation procedures are set up so that it is not necessary to derive strain cycle amplitudes. The operating principle of the counters, however, does permit the strain counter to operate in a cycle counting mode as described below and appears to have some potential when the trip and reset levels are arranged properly.

5.4 A Strain-Cycle Counter Concept for Fatigue Damage Monitoring

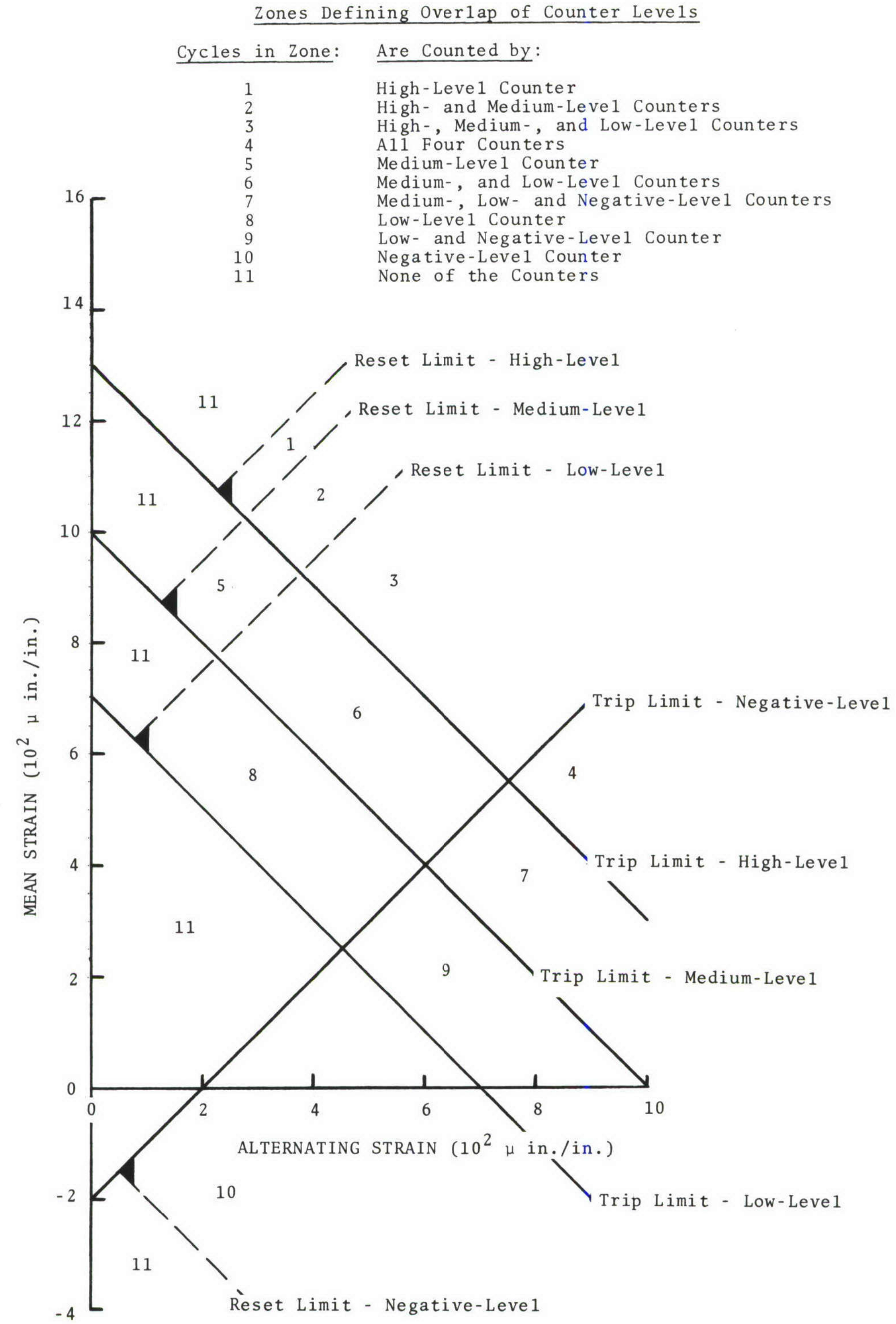
In computing the fatigue damages from the strain counter data, it was necessary to understand the operation of the counter in counting cycles. To this end, Figure 9a was prepared to illustrate the combinations of mean stress SM and alternating stress SA which would cause a counter with trip level T and reset level R to register a count. As noted in this figure, any cycle in zone 1 would be counted but those in zone 2 would not exceed the trip level, those in zone 4 would not fall below the reset level, and those in zone 3 would not cross either the trip or the reset levels.



Note: Only cycles with (SM+SA) > T and (SM-SA) < R will cause the counter to register a count. Graphically, cycles in zone 1 will be counted; those in zones 2, 3 and 4 will not be counted.

a) Cycles Which Trip a Counter Having Trip Strain T and Reset Strain R

Figure 9. Illustration of Strain-Level Counter and Strain-Cycle Counter Operation

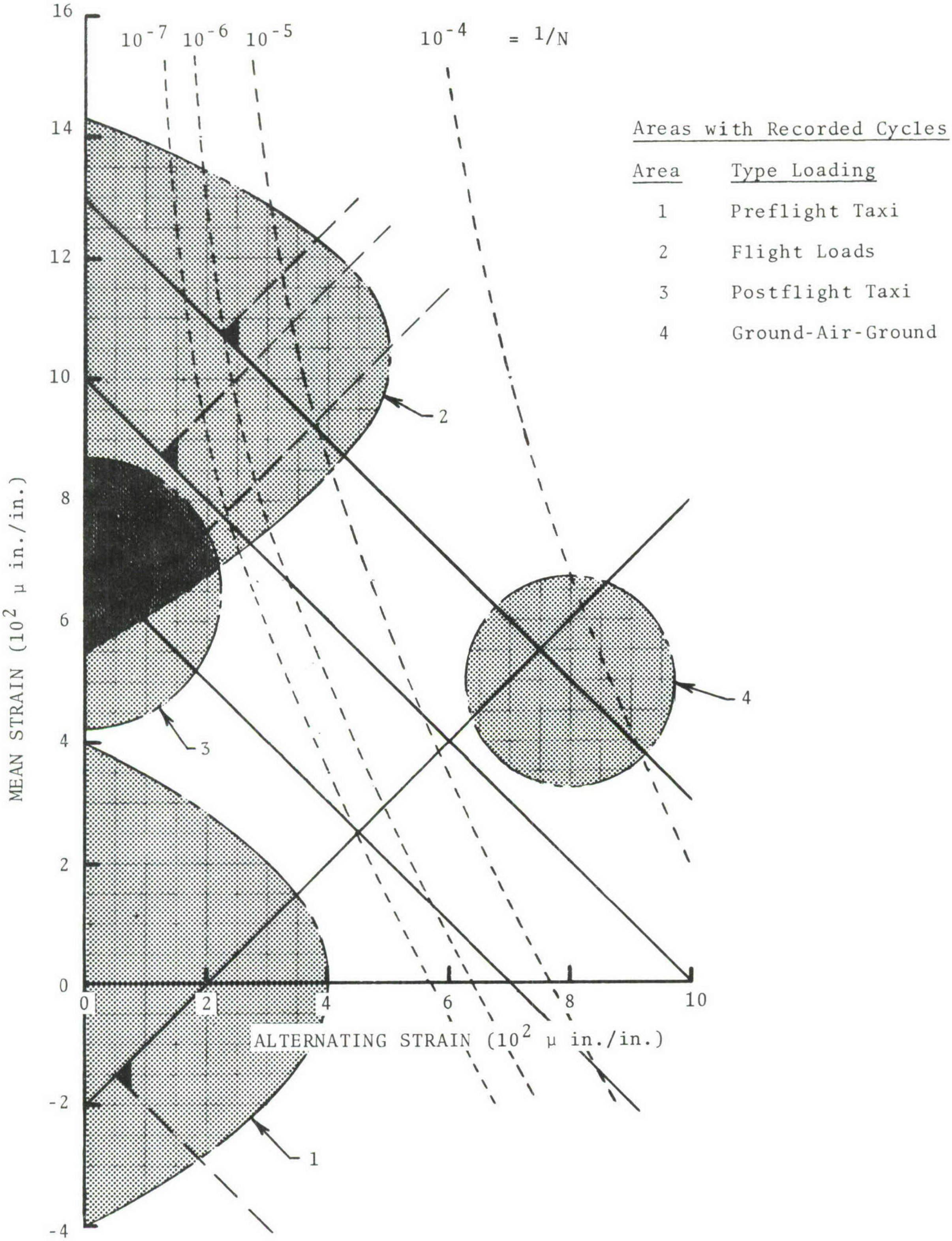


Zones Defining Overlap of Counter Levels

Cycles in Zone:	Are Counted by:
1	High-Level Counter
2	High- and Medium-Level Counters
3	High-, Medium-, and Low-Level Counters
4	All Four Counters
5	Medium-Level Counter
6	Medium-, and Low-Level Counters
7	Medium-, Low- and Negative-Level Counters
8	Low-Level Counter
9	Low- and Negative-Level Counter
10	Negative-Level Counter
11	None of the Counters

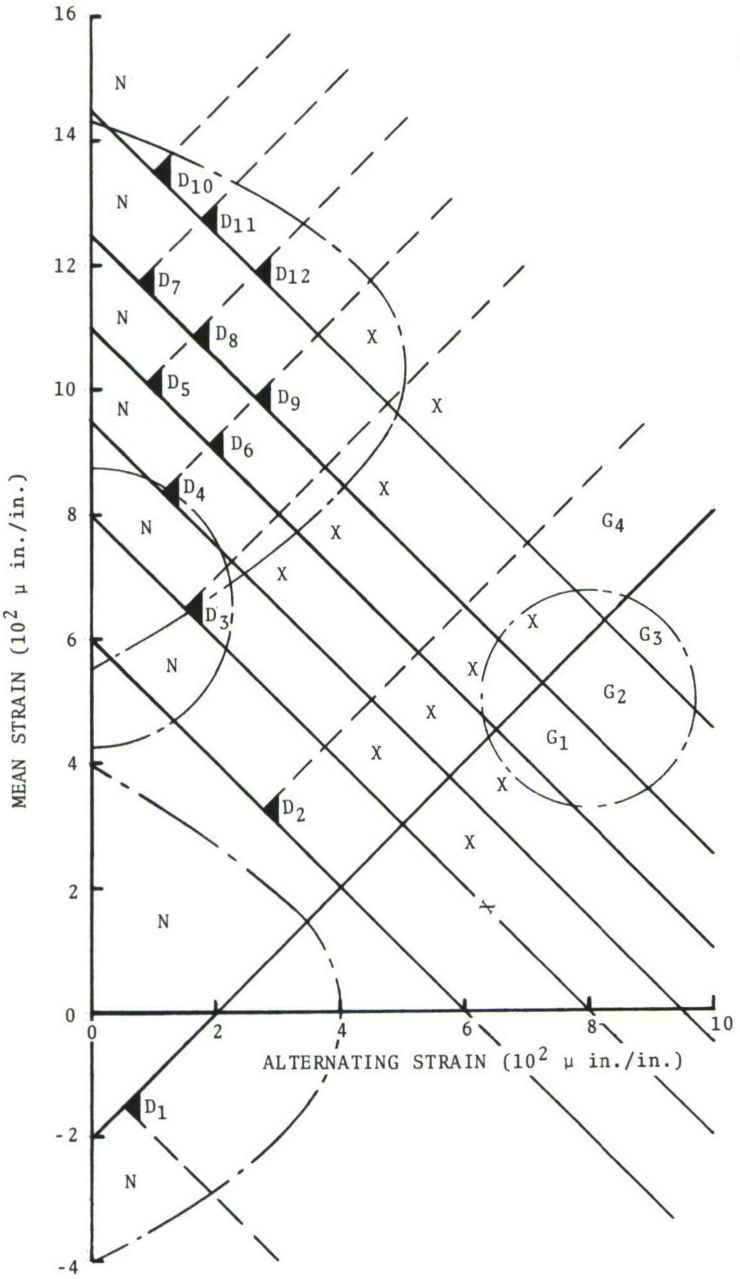
b) Cycles Counted by the NASA Strain-Level Counter on the A-37B

Figure 9 - Continued



c) Normal Operating Areas for Strain Cycles on the A-37B Lower Wing Spar

Figure 9 - Continued



DAMAGE BY ZONE

Zone	$1/(N\text{x}10^{-6})$	$1/(N\text{x}10^{-6})$/Count*
D_1	0	0
D_2	0	0
D_3	0.10	0.10
D_4	0.30	0.30
D_5	0.25	0.25
D_6	2.13	1.58
D_7	0.10	0.10
D_8	2.50	2.15
D_9	9.10	4.47
D_{10}	0.50	0.50
D_{11}	4.76	4.16
D_{12}	16.10	8.84
G_1	28.60	**
G_2	52.60	**
G_3	120.00	**
G_4	91.00	**
N	0	0
X	***	***

* Adjusted for overlap of Counter zones.

** GAG cycle obtained by subtracting 1.0 from all Counter outputs after a flight.

*** These zones were assumed to contain no cycles.

d) A 12-Level "Strain-Cycle Counter" Operation and Assigned Damages for Each Count from A-37B Lower Wing Spar Data

Figure 9 - Concluded

The operation of the NASA Strain Counter during the present program is shown in Figure 9b. As shown here, several zones exist which contain cycles which register in more than one counter while in other zones the cycles register in only one of the counters. Thus, after the counts are recorded, it is impossible to determine the number of cycles in any one of the zones.

Figure 9c indicates the NASA Strain Counter operation, with shaded areas representing the recorded A-37B data from England Air Force Base. Also shown on this figure are lines of constant fatigue damage which indicate that all of the damage on the lower wing surface is caused by flight operation and the GAG cycles.

An attempt was made to improve the fatigue damage accuracy of a strain counter by attempting to isolate the magnitude of the mean and alternating stresses for each recorded cycle. Assuming previous knowledge of the range of normal operating strains and the type of cycles which contributed the significant damage, a twelve-level "strain-cycle counter" was devised as illustrated in Figure 9d. With a trip/reset operation similar to that of the NASA strain counter, this counter has the trip and reset levels adjusted as listed in Table VII so that the number of cycles in each zone can be determined from the counts registered by each counter. Typical SM and SA values were assigned for cycles in each zone, and the fatigue damage per cycle was computed. Since cycles in some zones were counted by more than one of the counters (D_1 through D_{12}), the damages were adjusted so that an incremental damage per count was assigned to each counter. The current data was available for each flight, and a GAG cycle was defined by reducing all recorded counts by one and assigning the GAG cycle a damage for zone G_1, G_2, G_3, or G_4.

TABLE VII. NOMINAL TRIP AND RESET STRAIN LEVELS FOR A HYPOTHETICAL STRAIN-CYCLE COUNTER

Counter No.	Strain (μ in./in.) Trip	Reset	Counter No.	Strain (μ in./in.) Trip	Reset
1	-200	-100	7	1250	725
2	600	50	8	1250	925
3	800	500	9	1250	1100
4	950	725	10	1450	925
5	1100	725	11	1450	1100
6	1100	925	12	1450	1250

The 26 flights recorded at England AFB were processed through a computer program which simulated the operation of the strain-cycle counter and obtained the frequencies listed in Table XI in the Appendix. Then fatigue damages were computed and compared with the electrical gage cycle data. These damages are listed in Table VIII. As shown in Figure 7, the errors in damage computed from the strain-cycle counter were less than half of those for any of the strain-level counters. Such a technique appears to have definite potential for use in fatigue monitoring.

TABLE VIII. FATIGUE DAMAGE $n/(N \times 10^{-6})$ BY FLIGHT DERIVED FROM A HYPOTHETICAL STRAIN-CYCLE COUNTER AND FROM AN ELECTRICAL GAGE OUTPUT TIME HISTORY ON THE LOWER WING SPAR OF AN A-37B AT ENGLAND AFB

FLIGHT NUMBER	CYCLE COUNTER	ELECTRICAL CYCLES
1	105.71	94.50
2	58.99	36.10
3	259.34	278.00
4	193.93	307.90
5	144.95	122.50
6	156.65	162.80
7	160.64	178.90
8	56.08	31.30
9	285.24	325.40
10	395.59	474.10
11	185.10	201.70
12	149.40	136.50
13	132.11	117.80
14	305.73	282.50
15	208.69	331.90
16	124.95	124.60
17	35.35	27.90
18	42.23	38.20
19	63.56	51.40
20	197.81	184.90
21	44.89	49.10
22	70.02	87.80
23	59.33	37.40
24	59.98	62.70
25	91.21	107.10
26	226.25	320.70

Successful use of a strain-cycle counter would require knowledge of the distribution of strain cycle magnitudes for the instrumented aircraft. The trip and reset levels would have to be chosen specifically for the aircraft type and structural location to be gaged. Analysis of the A-37B data to determine the percentage of total damage recorded by each of the twelve counters indicates that some of the counters contributed little or nothing to the total damage values. However, it would be necessary, in a fatigue monitoring application, to assign some counters to record the GAG cycles. It appears that a strain-cycle counter with 8 to 12 levels would adequately monitor fatigue damage on A-37B aircraft.

Initial investigation of the circuitry of the NASA Strain Counter indicates that modifications would have to be made to permit the freedom of adjustment of trip and reset levels necessary in the strain-cycle counter concept.

To adequately test the potential of a strain-cycle counter device,

a) a strain-cycle counter should be designed and built to monitor damage on a current-generation aircraft such as the A-37B,
b) this strain-cycle counter should be evaluated in laboratory tests for proper operation under simulated flight conditions, and
c) several strain-cycle counters should be installed on operational aircraft to evaluate their performance under fleet conditions and their acceptance by flight and maintenance crew personnel. These aircraft should also be equipped with a proven damage monitoring device to be used as a standard in evaluating the strain-cycle counters.

6. SUMMARY AND CONCLUSIONS

a) Within the evaluation constraints of comparing the NASA Strain Counter data with the digitally recorded strain gage data, the counter operated according to its specifications and recorded data with no evidence of instrument malfunctioning during 26 flights of an A-37B aircraft.

b) The comparison of fatigue damages computed from hypothetical strain-level counters with fatigue damages computed from cycles derived from a recorded strain time history indicated that a level-crossing counter device cannot duplicate the results of a strain time history recorder. No suitable way of deriving cycles from the level-crossing data was found.

c) Varying the number of strain levels in the level-crossing data did not appreciably affect the fatigue damage results. There was no definite tendency for the computed damage to increase or to decrease as the number of levels was increased from four to sixteen.

d) Preliminary results from a hypothetical strain-cycle counting device with 12 counters indicate that such a device has definite potential as a fatigue damage monitoring device. This strain-cycle counting device is similar to the NASA Strain-Level Counter but has much more flexibility in the adjustment of the trip and reset levels.

APPENDIX

TABULATED COUNTS FOR HYPOTHETICAL STRAIN-LEVEL AND STRAIN-CYCLE COUNTERS

TABLE IX. COMPARISON OF COUNTS PER FLIGHT FOR EACH LEVEL OF FOUR HYPOTHETICAL STRAIN-LEVEL COUNTERS ON THE LOWER WING SPAR OF AN A-37B AT ENGLAND AFB

a) Four-Level Counter

FLIGHT NUMBER	STRAIN ■MICROIN/IN■			
	-200	700	1000	1300
1	0	3	3	1
2	22	7	4	0
3	23	26	8	3
4	39	55	3	2
5	38	10	8	3
6	3	8	3	2
7	0	55	11	7
8	45	265	2	0
9	11	39	21	6
10	30	118	31	17
11	31	47	13	13
12	539	5	2	2
13	463	24	2	1
14	4	4	18	12
15	108	355	14	6
16	180	68	30	5
17	194	114	6	0
18	123	29	9	0
19	38	121	3	1
20	293	202	10	4
21	152	218	32	0
22	1	114	12	2
23	200	63	12	0
24	101	12	7	1
25	261	84	10	4
26	478	26	12	4

b) Eight-Level Counter

FLIGHT NUMBER	STRAIN ■MICROIN/IN■							
	-300	-200	400	600	800	1000	1200	1400
1	0	0	9	2	50	3	2	1
2	4	22	39	4	72	4	2	0
3	1	24	27	1	26	8	4	2
4	8	39	7	1	157	3	2	2
5	3	38	5	1	202	8	5	1
6	0	3	10	1	111	3	3	1
7	0	0	7	1	43	11	13	4
8	6	45	22	2	30	2	2	0
9	1	11	21	4	138	21	6	5
10	3	30	8	4	227	31	13	10
11	2	31	4	9	201	13	14	3
12	171	594	2	1	173	2	2	1
13	267	790	1	4	111	2	3	1
14	0	4	9	1	14	18	14	6
15	13	109	5	3	8	14	3	4
16	37	180	13	4	14	30	7	0
17	56	195	2	40	9	6	0	0
18	11	123	6	2	2	9	1	0
19	3	38	6	1	4	3	1	0
20	58	294	3	4	66	10	5	3
21	49	152	2	7	34	32	2	0
22	0	1	2	7	34	12	4	1
23	9	200	3	16	15	12	1	0
24	8	101	5	3	7	7	2	0
25	38	261	2	3	9	10	6	2
26	106	482	2	1	4	12	5	4

TABLE IX - Continued

c) Twelve-Level Counter

FLIGHT NUMBER	STRAIN ▪MICROIN/IN▪											
	-300	-200	300	400	600	700	900	1000	1100	1200	1300	1400
1	0	0	41	9	1	1	2	3	3	2	1	1
2	4	22	212	39	4	7	4	4	4	2	0	0
3	1	24	94	27	1	26	3	8	7	4	3	2
4	8	39	21	7	1	55	10	3	2	2	2	2
5	3	38	22	5	1	10	12	8	4	5	3	1
6	0	3	74	10	1	8	3	3	3	3	2	1
7	0	0	6	7	1	55	4	11	11	13	7	4
8	6	45	82	22	2	265	11	2	2	2	0	0
9	1	11	97	21	4	39	36	21	8	6	6	5
10	3	30	53	8	4	118	63	31	16	13	17	10
11	2	31	29	4	9	47	27	13	12	14	13	3
12	171	594	3	2	1	5	10	2	2	2	2	1
13	267	790	4	1	4	24	10	2	2	3	1	1
14	0	4	71	9	1	4	7	18	16	14	12	6
15	13	109	14	5	3	355	4	14	8	3	6	4
16	37	180	61	13	3	68	13	30	13	7	5	0
17	56	195	3	2	40	114	7	6	3	0	0	0
18	11	123	45	6	1	29	6	9	4	1	0	0
19	3	38	45	6	1	121	3	3	3	1	1	0
20	58	294	16	3	4	202	12	10	8	5	4	3
21	49	152	12	2	7	218	17	32	8	2	0	0
22	0	1	5	2	7	114	3	12	7	4	2	1
23	9	200	12	3	16	63	11	12	3	1	0	0
24	8	101	17	5	2	11	2	7	5	2	1	0
25	38	261	17	2	3	84	5	10	5	6	4	2
26	106	482	14	2	1	26	5	12	7	5	4	4

TABLE IX - Concluded

d) Sixteen-Level Counter

FLIGHT NUMBER	STRAIN ▪MICROIN/IN▪															
	-400	-300	-200	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
1	0	0	0	95	41	9	2	1	1	50	2	3	3	2	1	1
2	0	4	22	610	212	39	7	4	7	72	4	4	4	2	0	0
3	0	1	24	411	94	27	5	1	26	26	3	8	7	4	3	2
4	0	8	39	151	21	7	2	1	55	157	10	3	2	2	2	2
5	0	3	38	120	22	5	1	1	10	202	12	8	4	5	3	1
6	0	0	3	358	74	10	1	1	8	111	3	3	3	3	2	1
7	0	0	0	6	6	7	4	1	55	43	4	11	11	13	7	4
8	1	6	45	284	82	22	5	2	265	30	11	2	2	2	0	0
9	0	1	11	405	97	21	5	4	39	138	36	21	8	6	6	5
10	0	3	30	303	53	8	2	4	118	227	63	31	16	13	17	10
11	0	2	31	214	29	4	5	9	47	201	27	13	12	14	13	3
12	24	171	594	11	3	2	1	1	5	173	10	2	2	2	2	1
13	40	267	790	13	4	1	1	4	24	111	10	2	2	3	1	1
14	0	0	4	455	71	9	1	1	4	14	7	18	16	14	12	6
15	0	13	109	72	14	5	1	3	355	8	4	14	8	3	6	4
16	2	37	180	288	61	13	2	3	68	14	13	30	13	7	5	0
17	6	56	195	49	3	2	4	40	114	9	7	6	3	0	0	0
18	0	11	123	227	45	6	2	1	29	2	6	9	4	1	0	0
19	0	3	38	188	45	6	1	1	121	4	3	3	3	1	1	0
20	4	58	294	110	16	3	1	4	202	66	12	10	8	5	4	3
21	4	49	152	44	12	2	1	7	218	34	17	32	8	2	0	0
22	0	0	1	25	5	2	2	7	114	34	3	12	7	4	2	1
23	2	9	200	68	12	3	6	16	63	15	11	12	3	1	0	0
24	0	8	101	97	17	5	1	2	11	7	2	7	5	2	1	0
25	0	38	261	77	17	2	1	3	84	9	5	10	5	6	4	2
26	19	106	482	78	14	2	1	1	26	5	5	12	7	5	4	4

TABLE X. COMPARISON OF COUNTS PER FLIGHT FOR EACH LEVEL OF FOUR HYPOTHETICAL STRAIN-LEVEL COUNTERS ON THE UPPER WING SPAR OF AN A-37B AT BINH THUY AB

a) Four-Level Counter

FLIGHT NUMBER	STRAIN ■MICROIN/IN■ -200	200	700	1000
1	2	443	9	1
2	4	114	75	2
3	0	0	7	242
4	1	163	42	1
5	0	1	11	191
6	0	0	12	145
7	0	4	615	0
8	0	19	66	0
9	0	7	596	14
10	0	0	459	14
11	0	23	759	3
12	0	12	724	0
13	0	69	21	0
14	0	53	635	0
15	0	56	534	1
16	0	75	1	0
17	0	425	0	0
18	0	0	414	43
19	0	37	746	2
20	0	44	604	0
21	0	527	7	0
22	0	153	574	0
23	0	45	582	1
24	0	18	26	0
25	0	8	53	4
26	0	7	26	1
27	0	16	3	0
28	0	29	1	0
29	0	3	5	0
30	0	5	2	0
31	0	8	19	0
32	0	4	73	0
33	0	1	52	2
34	0	1	11	19
35	0	1	97	5

b) Eight-Level Counter

FLIGHT NUMBER	STRAIN ■MICROIN/IN■ -400	-200	200	400	600	800	1000	1400
1	0	2	443	167	51	6	1	0
2	4	7	117	908	236	25	2	0
3	0	0	0	0	7	24	242	0
4	0	1	163	737	214	12	1	0
5	0	0	1	3	11	28	191	1
6	0	0	0	6	12	61	145	1
7	0	0	4	119	614	17	0	0
8	0	0	19	197	667	14	0	0
9	0	0	7	43	427	207	14	0
10	0	0	0	14	198	220	14	0
11	0	0	23	164	759	75	3	0
12	0	0	12	248	724	3	0	0
13	0	0	69	477	578	4	0	0
14	0	0	53	354	635	4	0	0
15	0	0	56	316	534	24	1	0
16	0	0	75	709	39	0	0	0
17	0	0	425	128	1	0	0	0
18	0	0	0	8	164	525	43	0
19	0	0	37	244	745	40	2	0
20	0	0	44	512	604	4	0	0
21	0	0	527	6	11	0	0	0
22	0	0	153	569	574	0	0	0
23	0	0	45	311	580	26	1	0
24	0	0	18	210	70	4	0	0
25	0	0	8	11	37	74	4	0
26	0	0	7	185	83	5	1	1
27	0	0	16	232	19	1	0	0
28	0	0	29	133	14	0	0	0
29	0	0	3	9	11	2	0	0
30	0	0	5	22	5	1	0	0
31	0	0	8	112	72	4	0	0
32	0	0	4	53	196	19	0	0
33	0	0	1	3	34	124	2	0
34	0	0	1	1	8	60	19	0
35	0	0	1	18	103	80	5	0

TABLE X - Continued

c) Twelve-Level Counter

FLIGHT NUMBER	STRAIN *MICROIN/IN*											
	-400	-200	200	300	400	500	600	700	800	900	1000	1400
1	0	2	443	915	167	174	51	9	6	1	1	0
2	4	7	117	400	908	442	236	75	25	5	2	0
3	0	0	0	0	0	3	7	7	24	117	242	0
4	0	1	163	615	757	179	214	42	12	3	1	0
5	0	0	1	2	3	6	11	11	28	93	191	1
6	0	0	0	1	6	17	12	12	61	237	145	1
7	0	0	4	37	119	323	614	615	17	3	0	0
8	0	0	19	66	197	529	667	66	14	1	0	0
9	0	0	7	17	43	138	427	596	207	59	14	0
10	0	0	0	2	14	48	198	459	220	50	14	0
11	0	0	23	64	164	342	759	759	75	14	3	0
12	0	0	12	62	248	550	724	724	3	0	0	0
13	0	0	69	230	477	577	578	21	4	1	0	0
14	0	0	53	162	354	634	635	635	4	0	0	0
15	0	0	56	149	316	527	534	534	24	2	1	0
16	0	0	75	269	709	845	39	1	0	0	0	0
17	0	0	425	498	128	33	1	0	0	0	0	0
18	0	0	0	1	8	41	164	414	525	128	43	0
19	0	0	37	98	244	459	745	746	40	10	2	0
20	0	0	44	166	512	600	604	604	4	0	0	0
21	0	0	527	902	6	11	11	7	0	0	0	0
22	0	0	153	340	569	574	574	574	0	0	0	0
23	0	0	45	113	311	570	580	582	26	8	1	0
24	0	0	18	81	210	267	70	26	4	0	0	0
25	0	0	8	7	11	20	37	53	74	19	4	0
26	0	0	7	64	185	223	83	26	5	2	1	1
27	0	0	16	116	232	128	19	3	1	0	0	0
28	0	0	29	96	133	71	14	1	0	0	0	0
29	0	0	3	8	9	12	11	5	2	0	0	0
30	0	0	5	11	22	16	5	2	1	0	0	0
31	0	0	8	39	112	216	72	19	4	0	0	0
32	0	0	4	11	53	212	196	73	19	0	0	0
33	0	0	1	1	3	12	34	52	124	14	2	0
34	0	0	1	1	1	4	8	11	60	87	19	0
35	0	0	1	4	18	57	103	97	80	22	5	0

TABLE X - Concluded

d) Sixteen-Level Counter

FLIGHT NUMBER	STRAIN ■MICROIN/IN■															
	-400	-300	-200	-100	100	200	300	400	500	600	700	800	900	1000	1200	1400
1	0	1	2	7	104	443	915	167	174	51	9	6	1	1	0	0
2	4	4	7	8	26	117	400	908	442	236	75	25	5	2	0	0
3	0	0	0	0	0	0	0	0	3	7	7	24	117	242	44	0
4	0	0	1	2	22	163	615	757	179	214	42	12	3	1	0	0
5	0	0	0	0	0	1	2	3	6	11	11	28	93	191	27	1
6	0	0	0	0	0	0	1	6	17	12	12	61	237	145	12	1
7	0	0	0	0	0	4	37	119	323	614	615	17	3	0	0	0
8	0	0	0	0	2	19	66	197	529	667	66	14	1	0	0	0
9	0	0	0	0	1	7	17	43	138	427	596	207	59	14	0	0
10	0	0	0	0	0	0	2	14	48	198	459	220	50	14	1	0
11	0	0	0	0	4	23	64	164	342	759	759	75	14	3	0	0
12	0	0	0	0	4	12	62	248	550	724	724	3	0	0	0	0
13	0	0	0	0	13	69	230	477	577	578	21	4	1	0	0	0
14	0	0	0	0	7	53	162	354	634	635	635	4	0	0	0	0
15	0	0	0	0	9	56	149	316	527	534	534	24	2	1	0	0
16	0	0	0	0	19	75	269	709	845	39	1	0	0	0	0	0
17	0	0	0	4	119	425	498	128	33	1	0	0	0	0	0	0
18	0	0	0	0	0	0	1	8	41	164	414	525	128	43	2	0
19	0	0	0	0	5	37	98	244	459	745	746	40	10	2	0	0
20	0	0	0	1	5	44	166	512	600	604	604	4	0	0	0	0
21	0	0	0	5	118	527	902	6	11	11	7	0	0	0	0	0
22	0	0	0	2	45	153	340	569	574	574	574	0	0	0	0	0
23	0	0	0	0	13	45	113	311	570	580	582	26	8	1	0	0
24	0	0	0	6	6	18	81	210	267	70	26	4	0	0	0	0
25	0	0	0	1	6	8	7	11	20	37	53	74	19	4	0	0
26	0	0	0	3	3	7	64	185	223	83	26	5	2	1	1	1
27	0	0	0	0	4	16	116	232	128	19	3	1	0	0	0	0
28	0	0	0	3	9	29	96	133	71	14	1	0	0	0	0	0
29	0	0	0	0	2	3	8	9	12	11	5	2	0	0	0	0
30	0	0	0	2	2	5	11	22	16	5	2	1	0	0	0	0
31	0	0	0	0	2	8	39	112	216	72	19	4	0	0	0	0
32	0	0	0	0	2	4	11	53	212	196	73	19	0	0	0	0
33	0	0	0	0	1	1	1	3	12	34	52	124	14	2	0	0
34	0	0	0	0	1	1	1	1	4	8	11	60	87	19	0	0
35	0	0	0	0	1	1	4	18	57	103	97	80	22	5	0	0

TABLE XI. COUNTS PER FLIGHT FOR EACH LEVEL OF A HYPOTHETICAL STRAIN-CYCLE COUNTER ON THE LOWER WING SPAR OF AN A-37B AT ENGLAND AFB

	LEVEL NUMBER											
FLIGHT NUMBER	1	2	3	4	5	6	7	8	9	10	11	12
1	0	1	1	1	1	6	2	2	5	1	2	2
2	22	1	1	4	4	4	1	1	1	0	0	0
3	23	1	1	5	5	63	2	27	91	3	8	8
4	39	1	7	5	2	30	1	8	24	4	6	6
5	38	1	1	7	4	35	2	5	5	1	1	1
6	3	3	2	3	3	13	3	5	17	2	2	2
7	0	3	2	5	5	48	4	16	29	1	2	2
8	45	3	2	2	2	8	1	1	1	0	0	0
9	11	6	5	25	5	48	4	18	30	7	10	10
10	30	3	17	27	11	115	5	36	51	10	12	12
11	31	3	9	15	10	51	10	28	42	0	0	0
12	539	3	2	2	2	13	2	5	8	2	2	2
13	463	3	2	4	2	15	2	2	4	1	1	1
14	4	3	2	14	14	42	10	16	46	6	8	8
15	108	3	2	12	6	19	1	9	14	5	6	6
16	180	3	3	26	11	52	4	13	13	0	0	0
17	194	3	3	8	3	3	0	0	0	0	0	0
18	123	3	1	8	4	24	0	0	0	0	0	0
19	38	2	2	3	3	12	1	3	4	0	0	0
20	293	3	5	9	7	23	2	9	10	4	4	4
21	152	3	9	20	4	30	0	0	0	0	0	0
22	1	3	3	12	5	22	1	3	3	0	0	0
23	200	3	1	14	3	3	0	0	0	0	0	0
24	101	3	2	5	4	8	1	1	2	0	0	0
25	261	3	3	8	3	41	1	12	12	0	0	0
26	478	2	2	6	5	54	1	8	13	6	7	7

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13. ABSTRACT

The NASA Electronic Strain-Level Counter was evaluated by analyzing the data recorded during 26 flights on an A-37B aircraft. The strain-level counter output was compared with data from a collocated strain gage recorded by a digital magnetic tape recorder. Fatigue damages were computed for several hypothetical strain-level counters to determine their suitability as fleet damage monitoring devices. Results indicated that the NASA strain-level counter performed according to its specifications but that the fatigue damages derived from the strain-level counter data did not agree with the fatigue damages derived from the strain time history data because of the inaccuracies associated with the conversion of level crossings to cycles. Increasing the number of strain levels of the hypothetical strain-level counters did not appreciably affect the damage results. However, a hypothetical variation of the strain-level counter, termed a "strain-cycle counter," did compute damages which duplicated those derived from the strain time history within acceptable limits. To determine its potential, a strain-cycle counter device should be designed, fabricated, and tested.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
fatigue monitoring						
strain recorder						
strain-level counter						
strain-gage instrumentation						

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