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# FLIGHT TEST EVALUATION OF A SCRATCH STRAIN GAGE

*T. L. HAGLAGE*

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The distribution of this report is limited because it describes tests and evaluation related to a military operational weapon system.

# FOREWORD

This report is the result of an in-house effort under Project 1467, "Structural Analysis Methods," Task 146704, "Structural Fatigue Analysis."

The item examined in this report is a commercial item that was not developed or manufactured to meet Government specifications, to withstand the tests to which it was subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on the commercial item discussed herein or on the manufacturer.

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# ABSTRACT

This report presents flight test results on the operation of the Prewitt Scratch Strain Gage. The program involved the use of a T-37B, which was previously instrumented for use as a flight loads survey aircraft. Three scratch gages were installed on the aircraft.

The flight program included individual high and low g maneuvers and also maneuvers taken from the Air Training Command flight syllabus. Data correletation between the electrical resistance gages and the scratch gages was accomplished.

The results indicate that the scratch strain gage is a feasible and reliable means of recording strain cycles of a character and magnitude found in a fighter aircraft structure.

Automated data reduction techniques and system applications of the gage are discussed.

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# LIST OF SYMBOLS

| SYMBOL | |
|---|---|
| G.G. | Installation gage gap |
| g | Acceleration produced by gravity |
| L | Spanning length of the gage |
| $n_Z$ | Normal load factor |
| W.S. | Aircraft wing station |
| $\epsilon$ | Material strain measured in inches/inch |
| $\mu\epsilon$ | Micro-strain — $\epsilon \times 10^{-6}$ |
| $\sigma$ | Applied stress on the material |
| $\Delta$ | Scratch gage reading minus electrical resistance gage reading |

# SECTION I

# INTRODUCTION

Individual aircraft within a fleet may accumulate damage at widely different rates due to variations in operational usage. It has been shown that total damage is not necessarily proportional to the number of flight hours. (Reference 1) Calculation of fatigue damage for sensitive areas of individual aircraft on a regular programmed basis, usually flight by flight, requires knowledge of damage accumulation rates in terms of basic mission parameters (gross weight, velocity, stores configuration, load level, etc.) for mission segments (taxi, takeoff, cruise, weapon release, etc.). Mission parameter input for the fatigue analysis is derived from structural flight load recorder programs which measure operational usage. The recorders are installed on only a small percentage of the total fleet. Cost and timely data reduction usually preclude instrumenting every aircraft. However, the results of Reference 1 suggest that, for fighter aircraft, it is necessary only to monitor the normal load factor during the combat phase of the mission. Knowledge of this single parameter in combination with store, gross weight, and appropriate flight log data would lead to an accurate assessment of the major portion of the fatigue damage accumulated during the total mission.

This implies also that a simple sensing device such as an accelerometer or strain gage could economically be utilized to obtain the normal load factor in a total fleet damage-monitoring program.

The study reviewed in this report presents a tail number damage-monitoring system adaptable to maneuvering load sensitive aircraft such as fighters and trainers. The heart of the system is the commercially available Prewitt Scratch Strain Gage. This device is a self-contained mechanical extensometer capable of measuring and recording total deformation (and thus average strain cycles over the effective installed gage length) of the aircraft member to which it is attached. (See Appendix for further description.)

An in-house laboratory evaluation program for the scratch gage has been completed with favorable results (Reference 2). The effort dealt mainly with the basic operation of the gage and with point-by-point data correlation with electrical strain gage readings. The report findings demonstrated that the gage is capable of accurately recording strains (tension and compression) of magnitudes found in fatigue-sensitive members of fighter aircraft.

The current evaluation program illustrates a potential system application of the scratch gage, that of fatigue damage monitoring of fighter aircraft by individual tail number. Three scratch gages were installed on a USAF T-37B for the purpose of determining sensitivity, capacity, and overall recording capabilities of the gage under actual flight conditions.

The aircraft used for this program was especially suited to scratch gage instrumentation, in that it was a flight loads survey aircraft involved in a flight test to determine stress levels in the lower front spar cap and lower front spar root fitting. Thirty-four electrical resistance strain gages (BLH type) were installed on the right wing in the area just described. An accelerometer was installed at the aircraft center of gravity. The scratch gages were installed in the critical spar region close to the electrical resistance strain gages so that data correlation between the two types of gages could be made. The spar geometry is especially suited to scratch gage installation because of the flat exposed flange which is of adequate width to accommodate the gage.

High positive and low negative g (acceleration of the center of gravity of the aircraft) loadings were experienced during eight individual flights of approximately one hour's duration each.

## SECTION II

## INSTALLATION OF GAGES

The installation of all gages on the T-37B was performed at Cessna Aircraft Company, Military Aircraft Division, Wichita, Kansas.

Scratch gages were installed on the outside surface of both main spars at the locations indicated in Figure 1. The midpoint of the gage spanning length was coincident with W.S. 64 in all locations. At the time of installation, the aircraft fuel tanks were empty.

The spar cap flange (Figure 2) was buffed with emery cloth at the point of the gage attachment to remove any paint or oxide coating on the surface to ensure adequate bonding. Each gage was then fastened to the exposed flange of the spar cap using epoxy adhesive. Pressure was applied to the gage ends on the upper wing surface during the curing period with metal "duck" weights as seen in Figure 3. Wooden props, shimmed up from the hangar floor, were used for the lower wing surface installation (Figures 4 and 5).

All of the above installation procedures for the three gages were performed in approximately one hour after the aircraft was rolled into the hangar. The adhesive was allowed to cure overnight.

During installation, the gage gap (Appendix) of all gages was set at 0.025 inches, a value predetermined based on an estimate of maximum strain expected and the equation $\epsilon_{max} = (0.056 - G.G.)/L$ (Reference 2).

To complete the gage installation, the brass recording discs were inserted and the stylus allowed to rest on the recording surface. Before each flight, the disc was manually rotated counterclockwise through a small angle to produce an arc A (Figure 6), which could later be used as a reference data point for strain measurement. The arc also provided an index to separate data on a flight-by-flight basis.

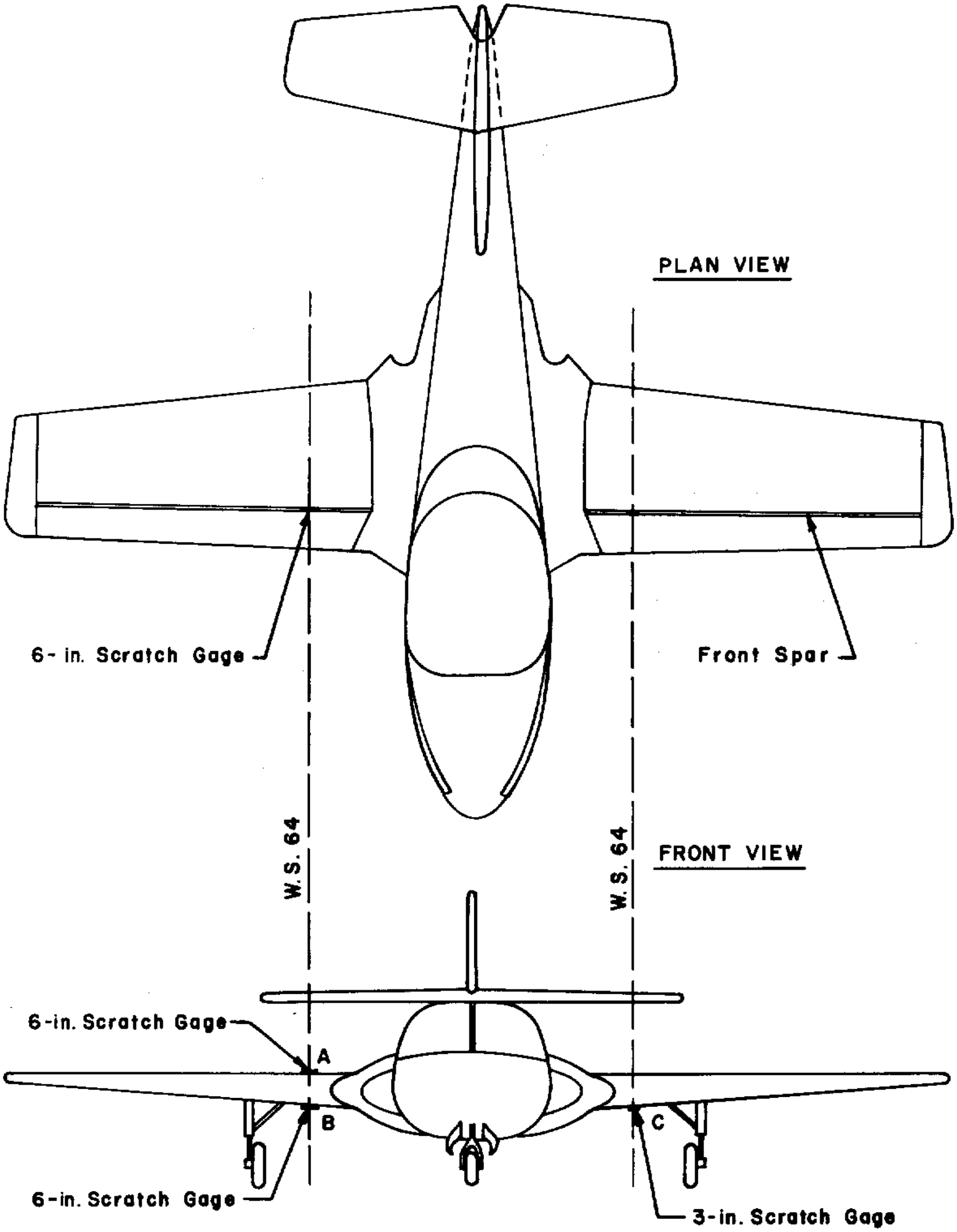

Figure 1. Plan View and Front View Of T-37B Illustrating Scratch Gage Locations

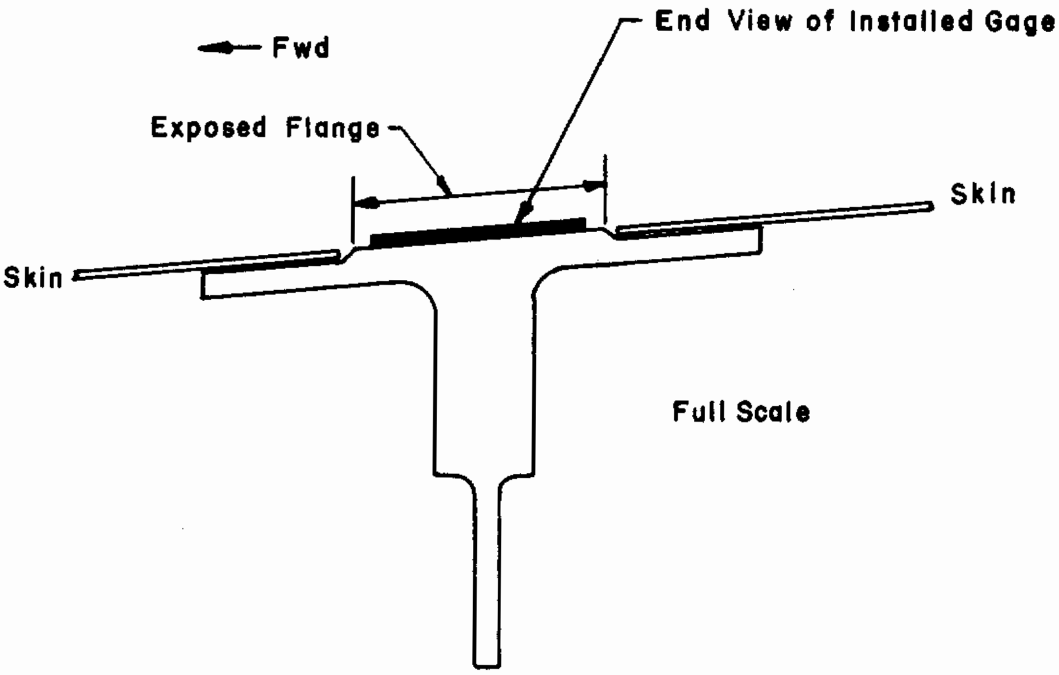

Figure 2.     Upper Spar Cap Cross Section

Figure 3. Six-Inch Scratch Gage Being Mounted On Upper Spar Cap

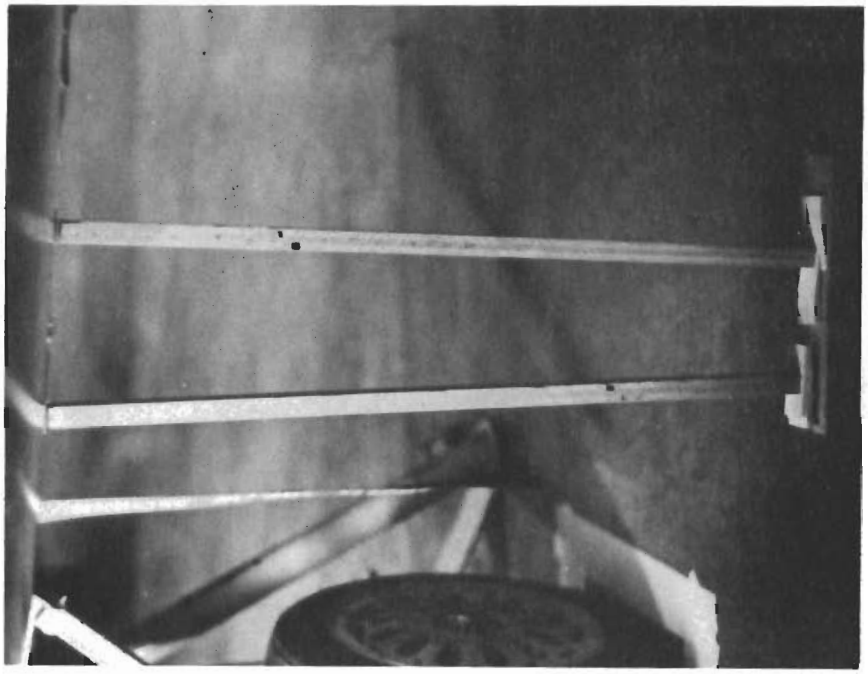

Figure 5. Pressure Application Using Wooden Props

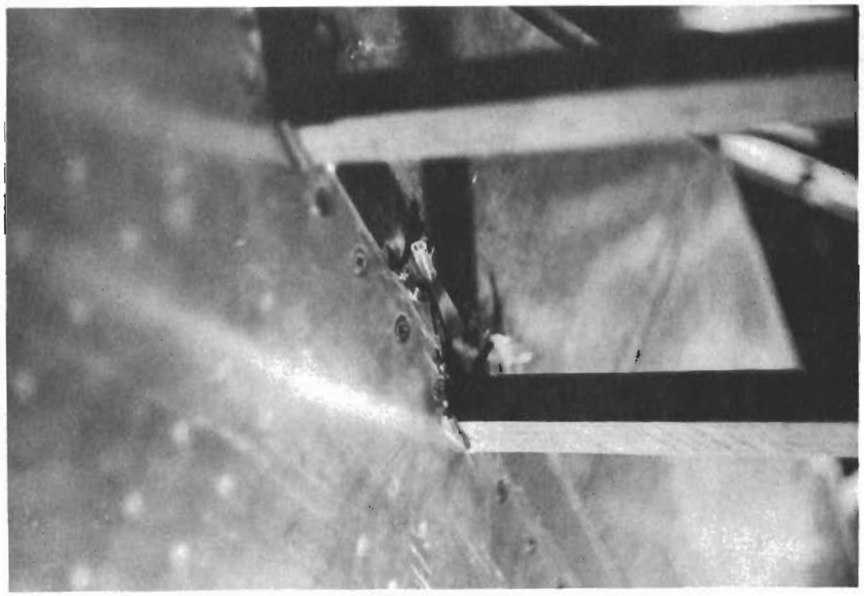

Figure 4. Installation of Six-Inch Scratch Gage On Lower Spar Cap

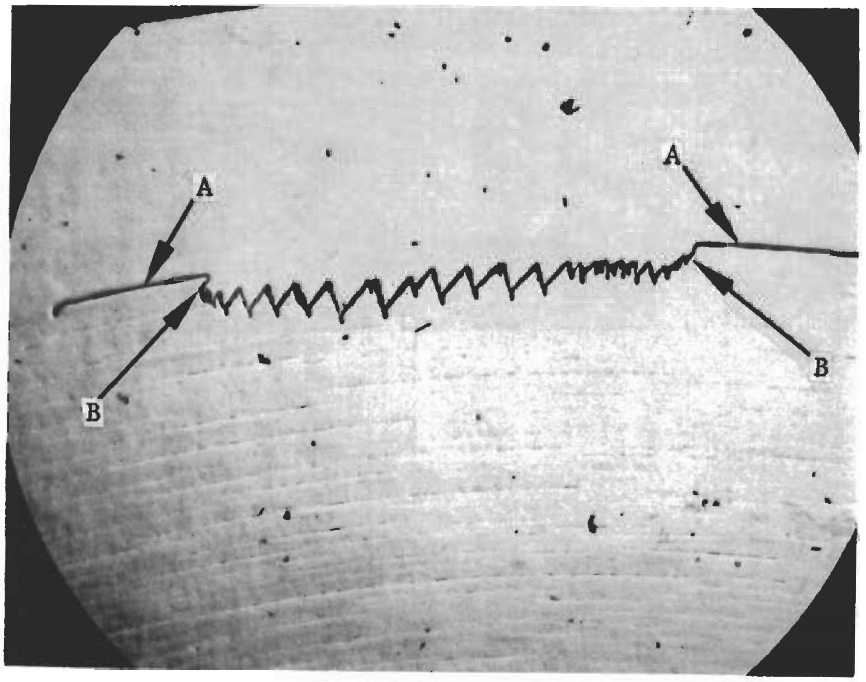

Figure 6. Photomicrograph Of Flight No. 1 Scratch Strain Record

The final step of the installation procedure was the fastening of a prefabricated cover over each gage (Figure 7). The cover for each gage was shaped from .020-inch aluminum sheets and was provided with a plexiglass window directly above the brass disc in order that the gage disc rotation could be observed without removing the cover. Strips of 3-inch wide adhesive tape were used to hold the cover in place, thus allowing easy removal for the purpose of gage inspection and flight indexing. The covers were required to protect the gages from foreign object damage during taxi, takeoff, and landing, and in addition, provided moisture-proofing protection since any ice formation could be detrimental to the gage operation. The covers projected approximately 1/4 inch above the wing surface but caused no apparent aerodynamic effects on the aircraft. The covers gave the desired protection for the gages during the entire flight program which lasted about three weeks. No de-bonding of the gages or covers occurred at any time during the program.

The thirty-four electrical resistance strain gages and the accelerometer were installed by Cessna personnel. The locations of the strain gages are shown by the various cross sections (Figure 8) of the right front spar lower cap. The accelerometer was located at the center of gravity of the aircraft, wing station (W.S) 0.00 inch.

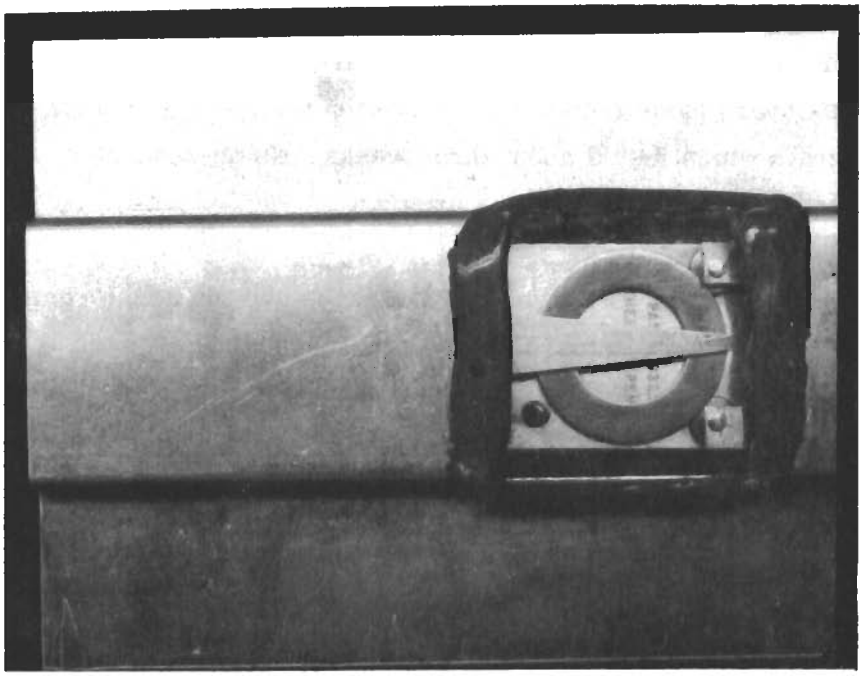

Figure 7. Gage Cover

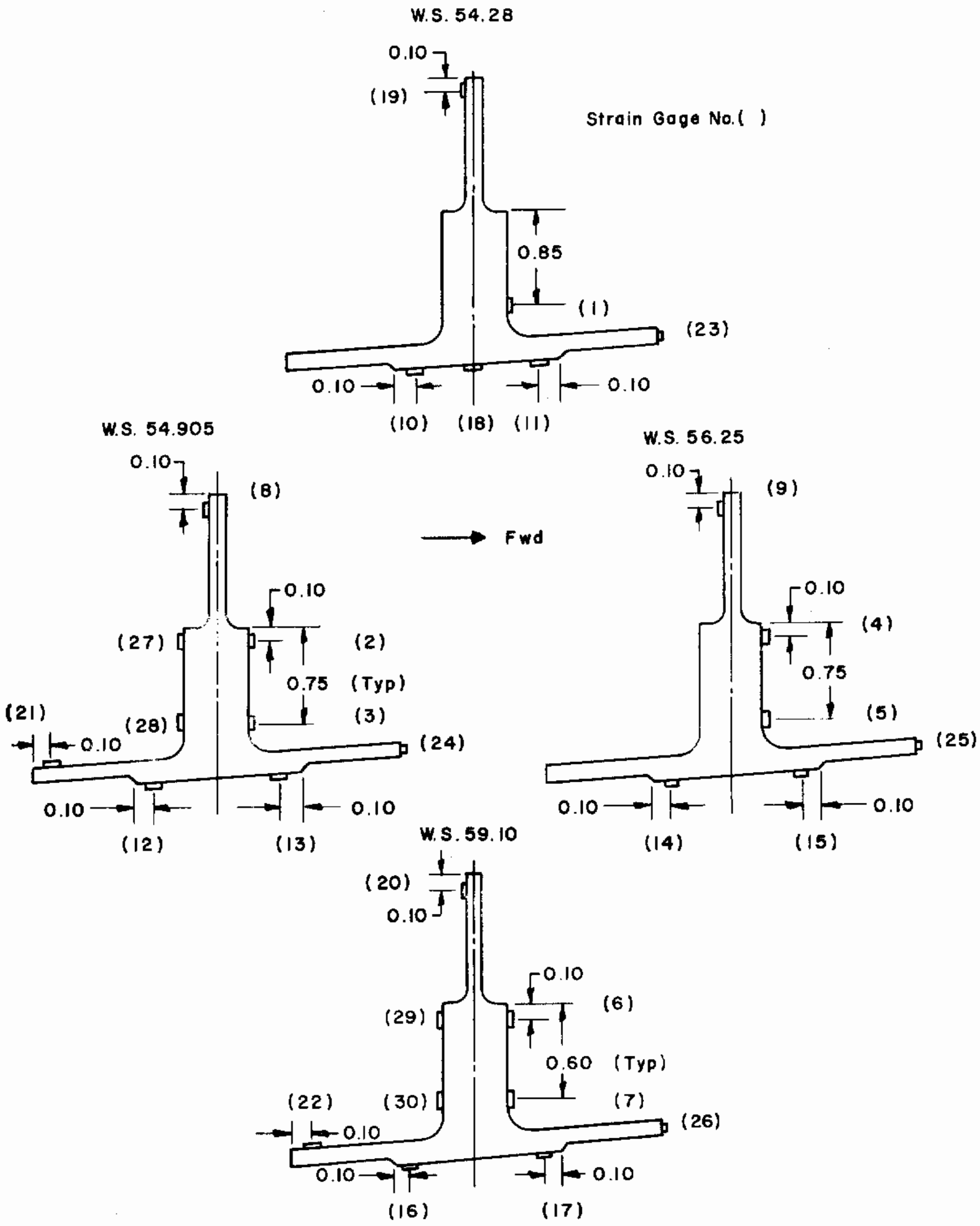

Figure 8. Electrical Resistance Strain Gage Locations

# SECTION III

# FLIGHT PROGRAM

There were two phases to the flight program (Reference 3). Phase I consisted of various low and high g maneuvers, as follows:

1) Level flight cruise
2) Positive maneuvers
    a) Approximately 4.0, 5.0, and 6.0 g's at minimum airspeed.
    b) Approximately 4.0, 5.0, and 6.0 g's at minimum airspeed of 370 knots.
3) Negative maneuvers at approximately -1.0 and -2.0 g's.
4) High speed LH and RH rolling pullouts at approximately 4.5 g's.
5) Landing impact at sink rates greater than 5 ft/sec (at high gross weight).

Phase II of the flight program consisted of individual maneuvers taken from the Air Training Command flight syllabus. The following is a list of these flight maneuvers.

1) Runaway trim
2) Recovery from vertical flight
3) Recovery from inverted flight
4) High speed dive recovery
5) Slow flight
6) Traffic pattern stalls
7) Spin recovery
8) Spin prevention
9) Simulated single-engine pattern and landing
10) Maximum performance climbing turn
11) Lazy eight
12) Aileron roll
13) Loop
14) Immelmann
15) Clover leaf
16) Barrel roll
17) Cuban eight

18) Split "S"
19) Power on stalls
20) Secondary stalls

Nine flights were required to complete Phases I and II with a total of 9 hours and 35 minutes of actual flight time logged. Visual Flight Rule Conditions prevailed at all times, with outside temperature approximately 31°F. Flight No. 1 (70 minutes' duration) and Flight No. 2 (45 minutes) were instrumentation check flights. Various adjustments and corrections (requiring a full work day) were needed for several of the electrical resistance strain gages and/or their oscillograph channels. The three scratch gages required no adjustment after the initial installation other than the manual disc rotation. Flight No. 3 (75 minutes) included all of the maneuvers from Phase I with the exception of the individual impact landings. Flight No. 4 (80 minutes), No. 5 (80 minutes), No. 6 (80 minutes), and No. 7 (65 minutes) consisted of the maneuvers from Phase II. Flights No. 8 (45 minutes) and No. 9 (35 minutes) accomplished the individual impact landings. The oscillograph traces for Flight No. 8 were unsatisfactory due to malfunctioning of electrical recording equipment, but the scratch gages functioned satisfactorily at all times.

## SECTION IV

## RESULTS

### 1. DISC CAPACITY

The capacity of the brass recording disc for any specific installation is dependent on the amplitude of the strains which it records, the frequency at which they occur, and the length of the gage. For the entire Phase I and II flight program described, the 3-inch gage disc rotated approximately 1/3 of a revolution (including the small flight index arcs). Each of the 6-inch gage discs rotated almost 1 1/2 revolutions, producing a trace overlap of about 1/2 revolution. More will be said concerning this overlapped portion later in this section.

It is obvious from the above discussion that the length of the gage does influence the amount of rotation of the discs indirectly since the smaller gust loads are not sensed by the shorter 3-inch gage, and there is consequently, no rotation. However, with the longer 6-inch gage, all load ranges of 1/2 g or more are recorded.

Based on these observances, it would be expected that the 3-inch-gage disc would make one full revolution with 30 hours of flight time similar to the flight program used herein. For similar usage, the 6-inch-gage disc should rotate completely with approximately seven hours of flight time. These time capacity estimates do not account for the manual indexing of the recording disc.

In actual operation, flight separation would normally not be necessary unless an indication of the maximum strain range (ground-air-ground) for each flight was desired.

### 2. TRACE CHARACTERISTICS

The minimum strain range value recorded by the 3-inch scratch gage was 600 $\mu\epsilon$ (Reference 2), which is more sensitive than the response level stated by the manufacturer, and in terms of center-of-gravity g loading, this is equivalent to individual occurrences of approximately 1.5 $\Delta g$. This means that all vibrations and even small gust accelerations were not sensed by the gage.

The 6-inch scratch gage on the lower right spar cap (B, Figure 1) had a minimum threshold strain range sensitivity of 250 $\mu\epsilon$ (Reference 2) and was capable of recording all $\Delta g$ loading occurrences of 1/2 g and greater. Thus, some gust loads and small secondary ranges in between primary peaks were sensed and registered. All gages performed equally well during the negative g maneuvers as during the positive regions. Individual sensitivity remained the same.

Figure 9 is a photomicrograph of the 3-inch gage recording of the entire Flight No. 5 (80 minutes). The large excursion in the center of the trace (A, Figure 9) represents a strain of 2340 $\mu\epsilon$ or a center-of-gravity acceleration of approximately 6 g's. After examining the pilot's log, it was discovered that this high load factor was produced during a recovery from a high speed dive. For the purpose of a visual comparison (Figure 10) a photomicrograph of the first half of Flight No. 5 recorded by the 6-inch gage, is presented, and includes the same large 6 g load recording (A, Figure 10). The magnification (25X) is the same for both photomicrographs, Figures 9 and 10. The recording of various small maneuver and gust loads (B, and C-Figure 10) are apparent in the 6-inch gage trace but are not present in the 3-inch gage trace.

The index arc, (A, Figure 6) which has been mentioned previously in this report, was made after each flight by a flight technician who manually rotated the disc a small amount in a counterclockwise direction. The disc will rotate in this direction only. It had been intended that this arc serve as a zero-strain reference for calibration purposes. However, this method was not acceptable as can be seen in Figure 6. Upon examination of the scratch trace, it was noted that each strain excursion returned to the same strain level. This, by definition, is the trim stress level or the stress level caused by a 1-g flight configuration. Calibration was therefore accomplished by using point B (Figure 6) as the true reference zero-strain level. This strain level is considerably different from strain level A (Figure 6), produced during rotation; one possible reason being that the disc was not rotated with a pure torque motion, but was pulled slightly away from the rollers. Another possibility is that the stylus arm moved laterally a small amount with the rotation of the disc and then sprang back. This motion produced the hook in the scratch from A to B (Figure 6).

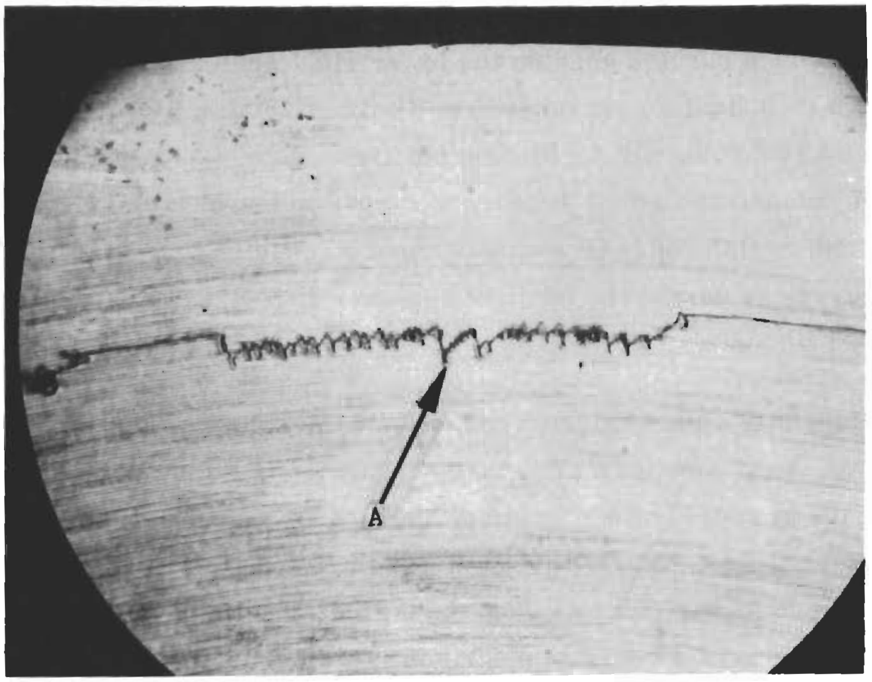

Figure 9. Three-Inch Gage Recording Of Flight No. 5

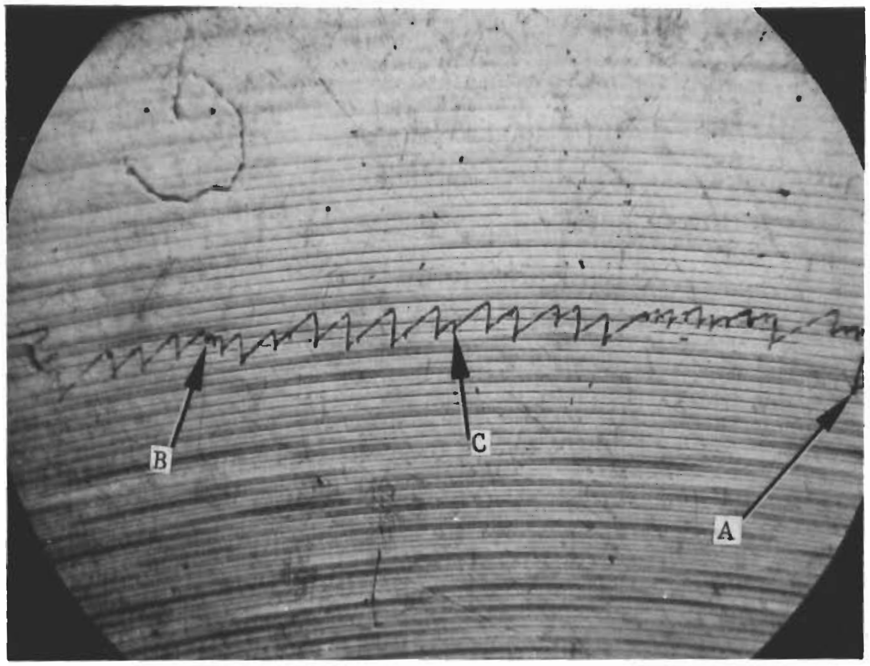

Figure 10. Six-Inch Gage Recording Of The First Half Of Flight No. 5

Means of alleviating this problem are under further investigation at the present time by the gage manufacturer. One solution which has been used is a complete circumferential scratch manufactured on the disc which is used as a reference strain level.

## 3. RECORDING AND DATA REDUCTION METHODS:

Of the 30 electrical resistance gages installed on the lower right spar cap, Nos. 16 and 17 were used to correlate strains because of their proximity to the scratch gage (Figure 11). Electrical strain gage data was recorded on a light beam oscillograph. A typical trace is included in Figure 12, along with a calibration which indicates that a deflection of 0.10 inches is equivalent to $100\mu\epsilon$. Due to paper capacity and speed, the oscillograph was controlled by the pilot and was only operated during significant portions of the flights such as high and low g occurrences, takeoff and landing, and other individual maneuvers. The effect of gust loads and other unscheduled loads were not recorded.

The scratch gage readings used in the strain correlation were obtained mainly from the 6-inch gage on the lower side of the right wing B, (Figure 1). The scratch gage, by its very nature, was never "turned off" and thus, during each flight, recorded all strain excursions encountered which were of a magnitude equal to or greater than its threshold sensitivity.

Two procedures were used to reduce the scratch data. Both were manual and employed different visual measuring techniques. The first method involved a closed circuit television camera which projected a magnified image of the scratch (2000-to-1 maximum) onto a 12 inch x 12 inch screen. As seen in Figure 13, the resolution of the scratches was of sufficient quality to permit measurement with a calibrated scale affixed to the television screen. A target rotating mechanism was used to pass the trace under the microscope. An entire trace was processed by this method using a level-crossing count method described in the next paragraphs. This task was accomplished in a few minutes with a reading tolerance of less than $50\mu\epsilon$ for the 6-inch gages. Incremental counting levels of $100\mu\epsilon$ were used.

The data reduction technique, termed the level-crossing count method, is one of the various counting methods which can be applied for the purpose of

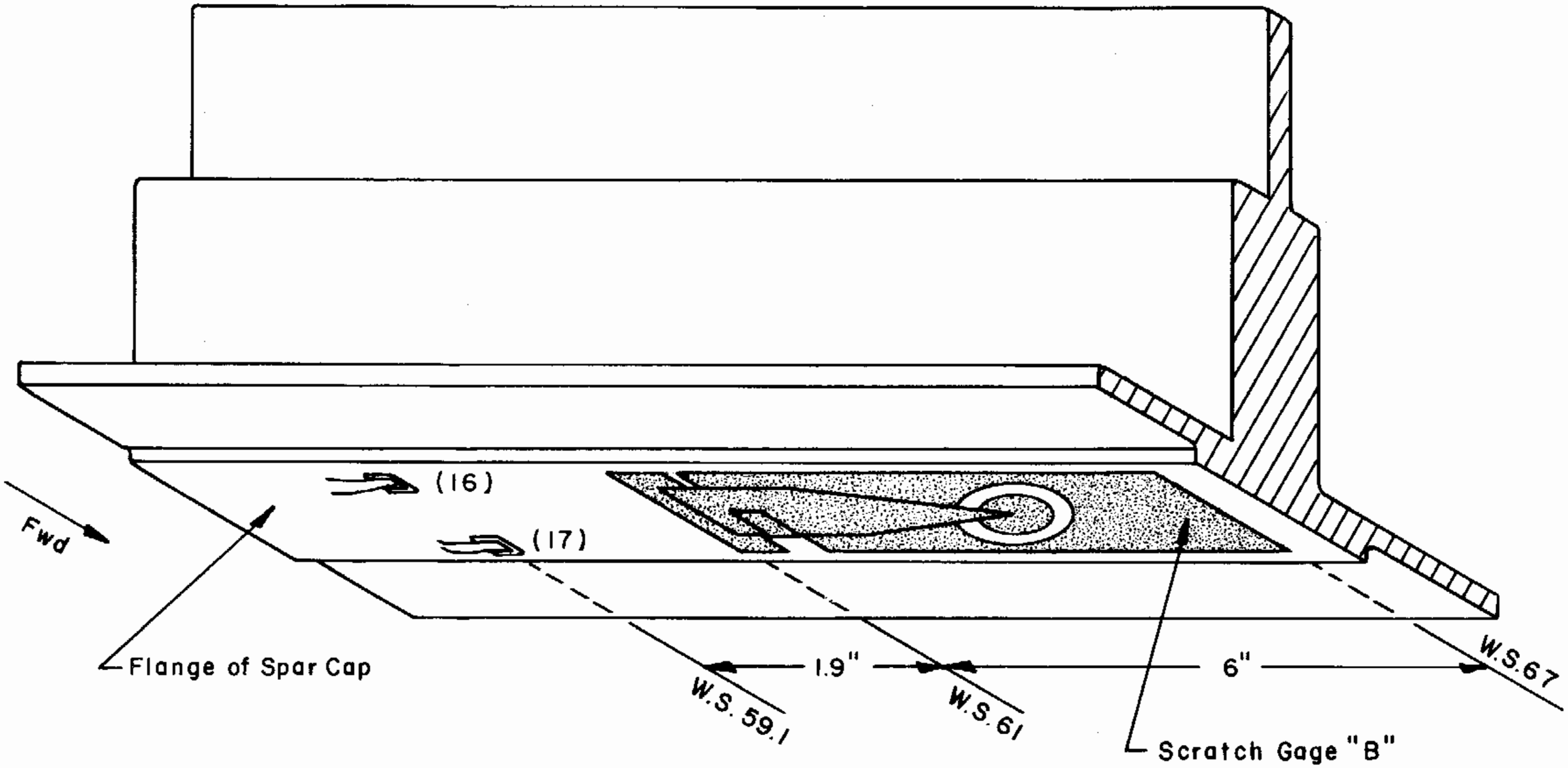

Figure 11. Location Of Gages On Right Lower Spar Cap

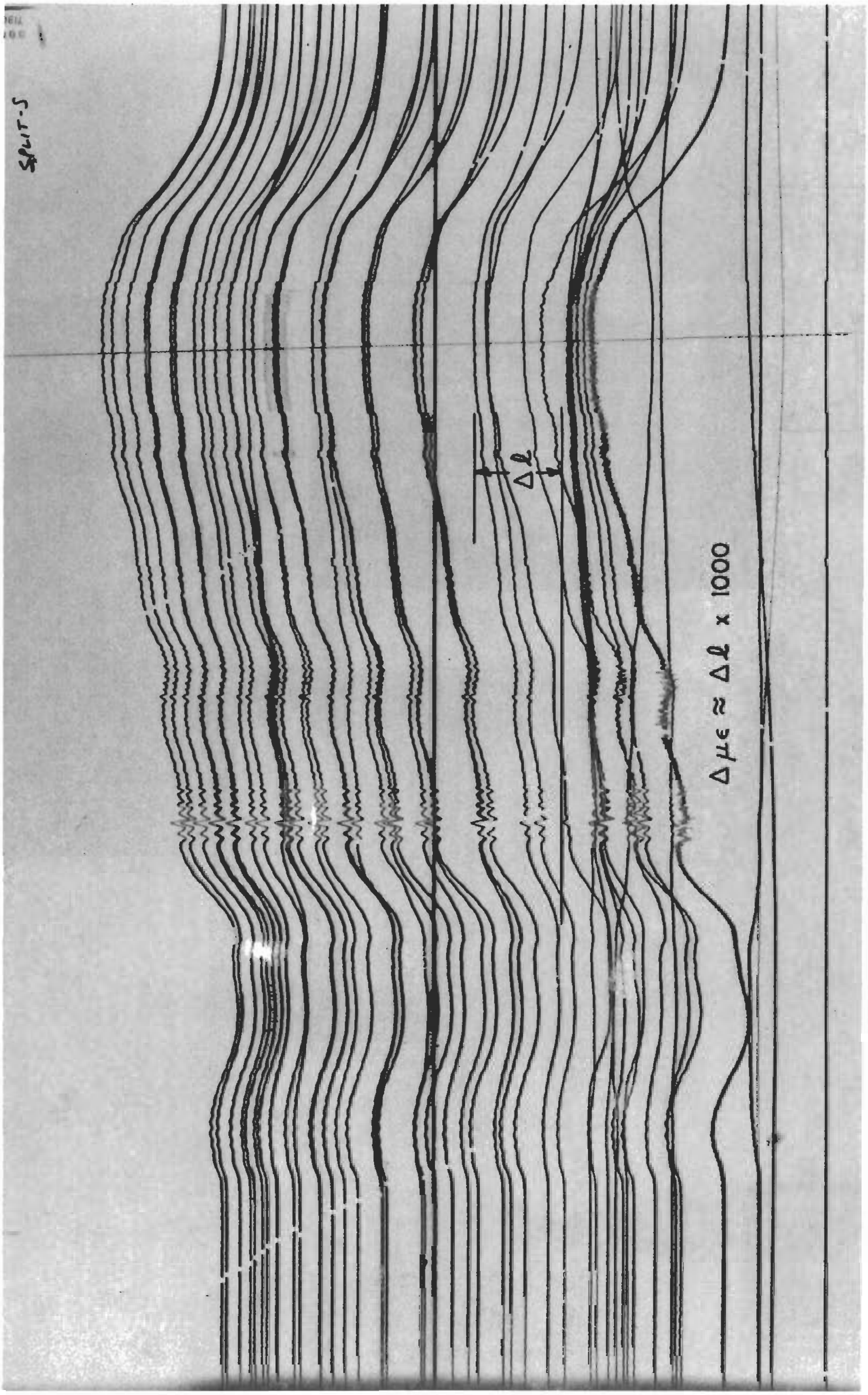

Figure 12. Light Beam Oscillograph Trace

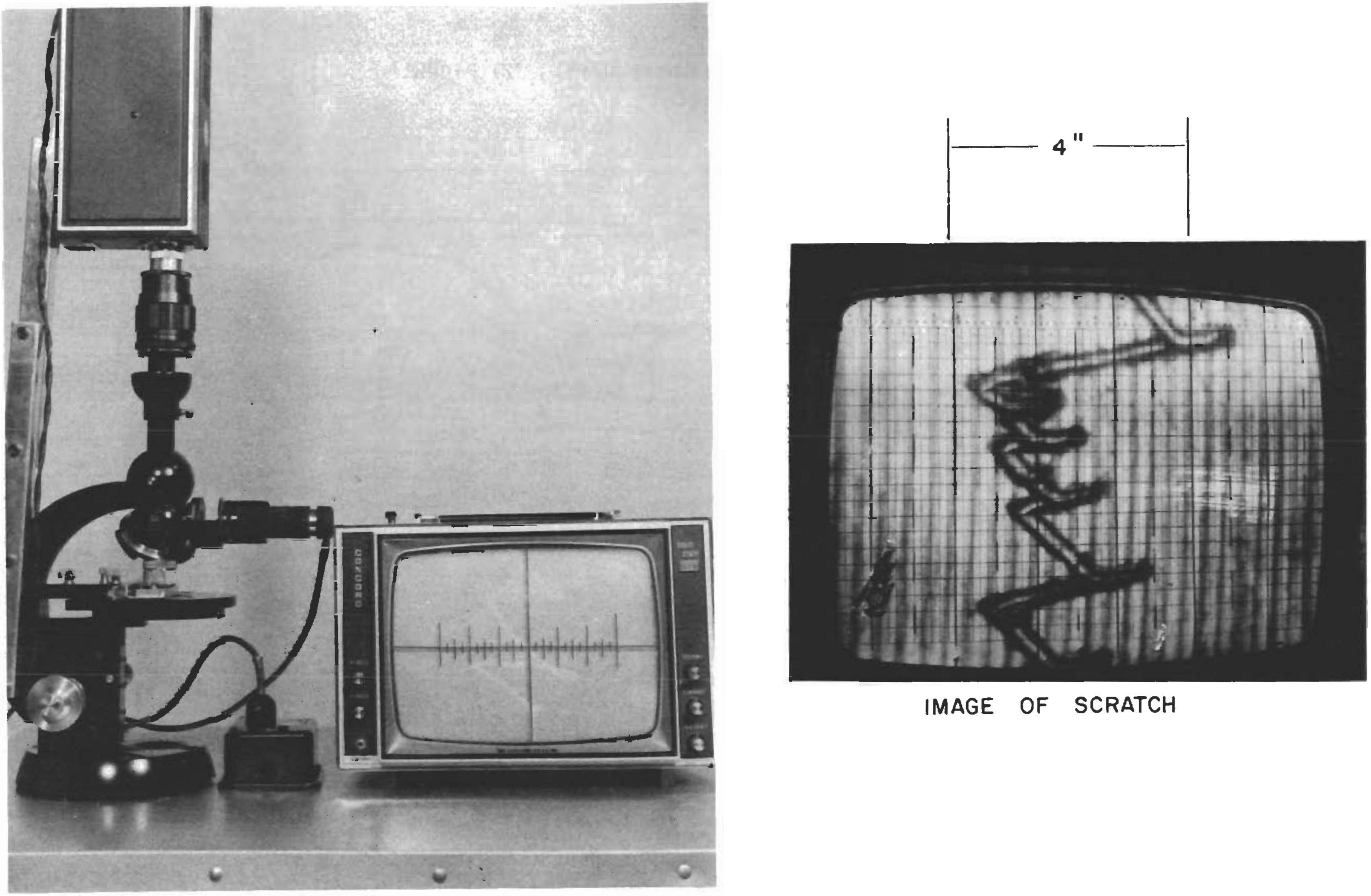

IMAGE OF SCRATCH

Figure 13. Television Camera Data Reduction System

analyzing load-time histories. By this method, a count is made each time the trace or scratch with a negative slope crosses a prescribed load level and these counts can be restricted to certain minimum and maximum load levels. This is illustrated in the sketch (Figure 14).

As stated earlier, the trace on the brass circular disc in the 6-inch gage did overlap. A photomicrograph of the overlapped portion is shown in Figure 15. It is evident that the path of one individual scratch is difficult and sometime impossible to follow. Since this problem exists, the occurrence data of an individual flight cannot be reduced but rather the data reduction must be based on the disc as a whole. The overlapped trace would not be detrimental to the level-crossing counting method as long as the counting was restricted to levels above or below the 0 to +1.5 g recording zone, since this might be obscure (Figure 15). The values of 0 and 1.5 were chosen since all small maneuver and gust loads occur within these boundaries. The level-crossing counting procedure was used on an overlapped recording on a disc from the 6-inch lower (underneath wing) gage. The results of this data retrieval are shown in Figure 16.

A single trace would be necessary for other types of counting methods, especially those involving strain ranges, since a critical and very meaningful range might extend from a positive value to a negative value or through the obscure region of the trace. Also, an overlapped trace should be avoided if automated data reduction techniques are used. These possible techniques will be presented in more detail later in the report.

The second approach which was used to reduce the data contained on the brass discs required the use of a calibrated microscope with a magnification factor of 50X. This arrangement made possible an analysis of a trace by the level-crossing count method also.

The reading tolerance using the calibrated microscope was again less than $50\mu\epsilon$ and usually within $30\mu\epsilon$ for the 6-inch gage.

To enhance the image of the scratch for measurement purposes, the scratch-recorded face of the brass disc was polished using a metallurgical specimen polisher. This reduced both the tarnish buildup on the disc and also unwanted

| RESULTS OF COUNTS | |
|---|---|
| g Level | Occurrence |
| - 1 | 1 |
| 2 | 4 |
| 3 | 3 |
| 4 | 1 |
| 5 | 1 |

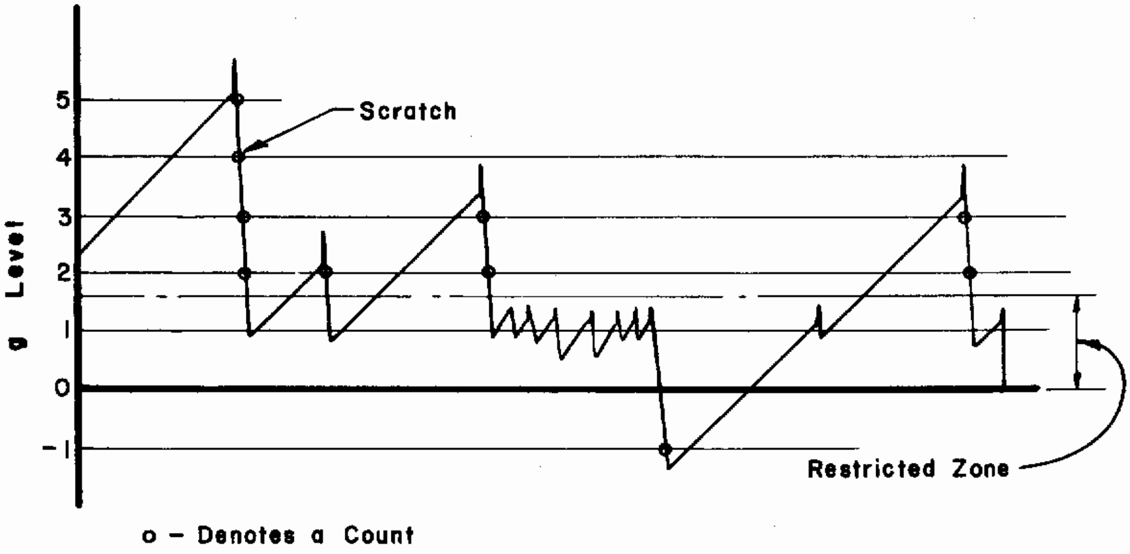

Figure 14. Level-Crossing Count Method

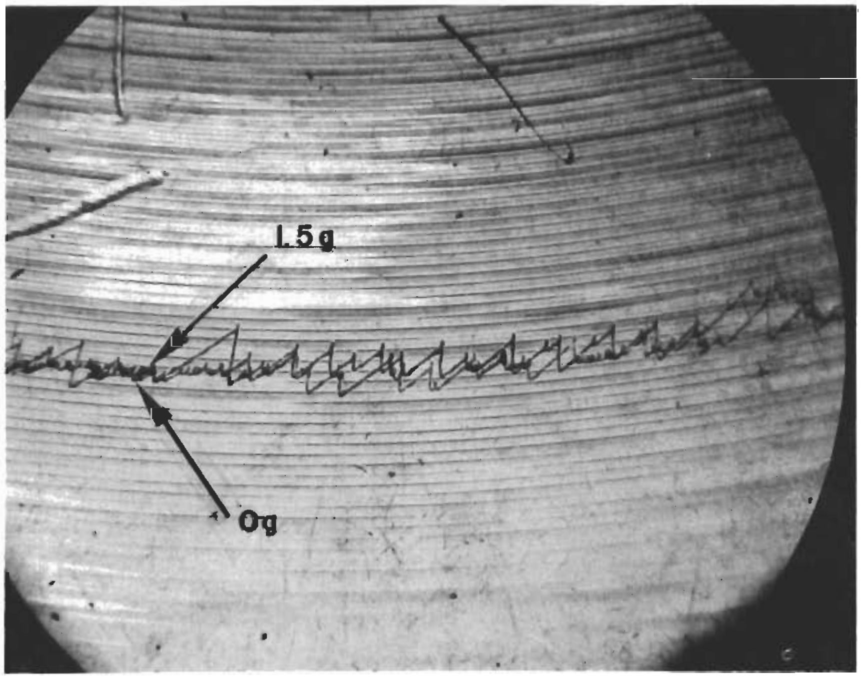

Figure 15. Photomicrograph Of Overlapped Scratch

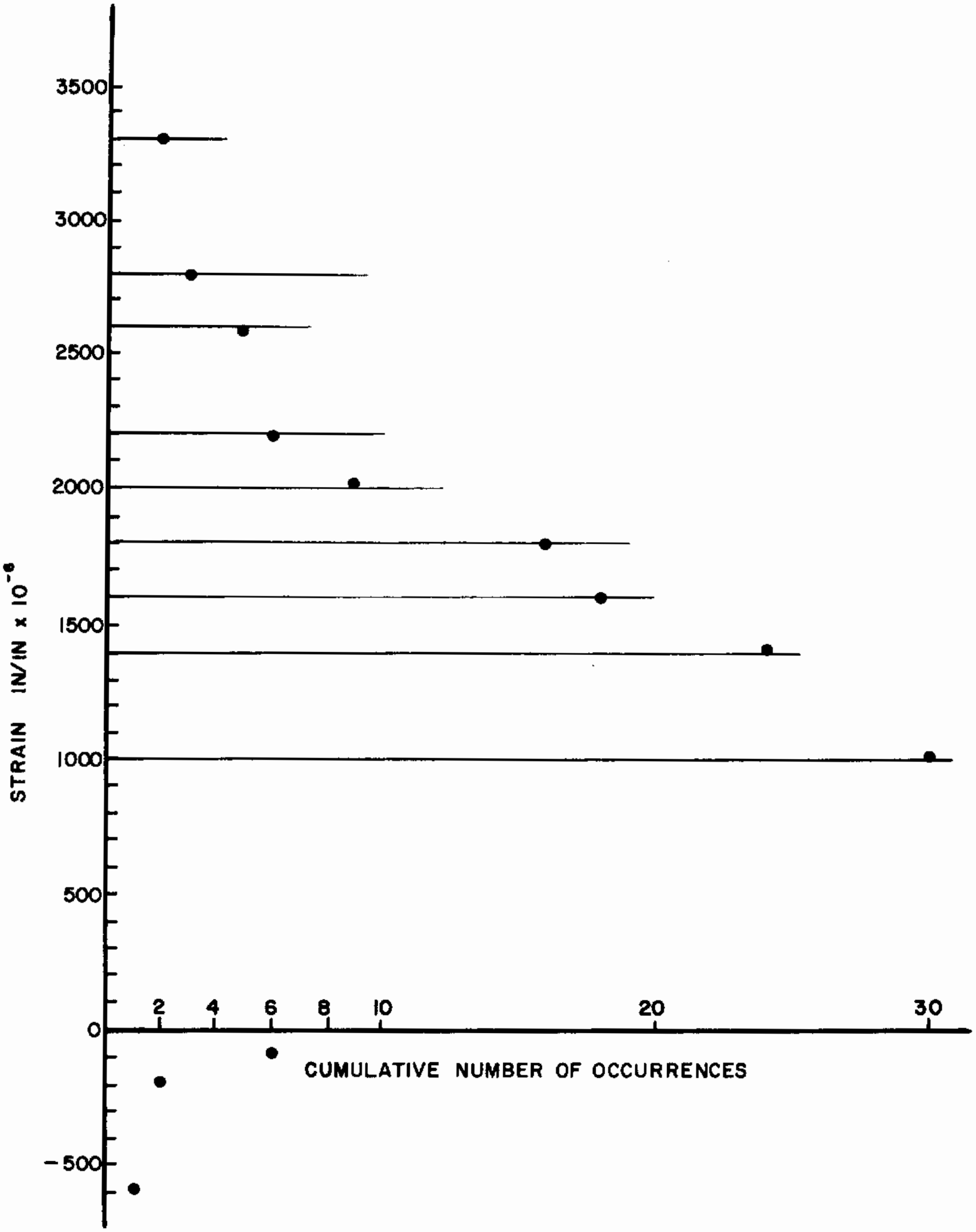

Figure 16. Strain Cumulative Occurrence Chart For 8-Hour Flight Program - Recorded By Gage B

scratches which occurred through handling and manufacturing. Figure 17 shows the disc in its unpolished condition. This can be compared to Figure 6 which is a portion of a polished disc. Although the scratch trace is not the same, the effect of the polishing is evident and it obviously increases not only the ease by which the trace can be read, but also the accuracy of determining the true maximums and minimums of the strain cycles.

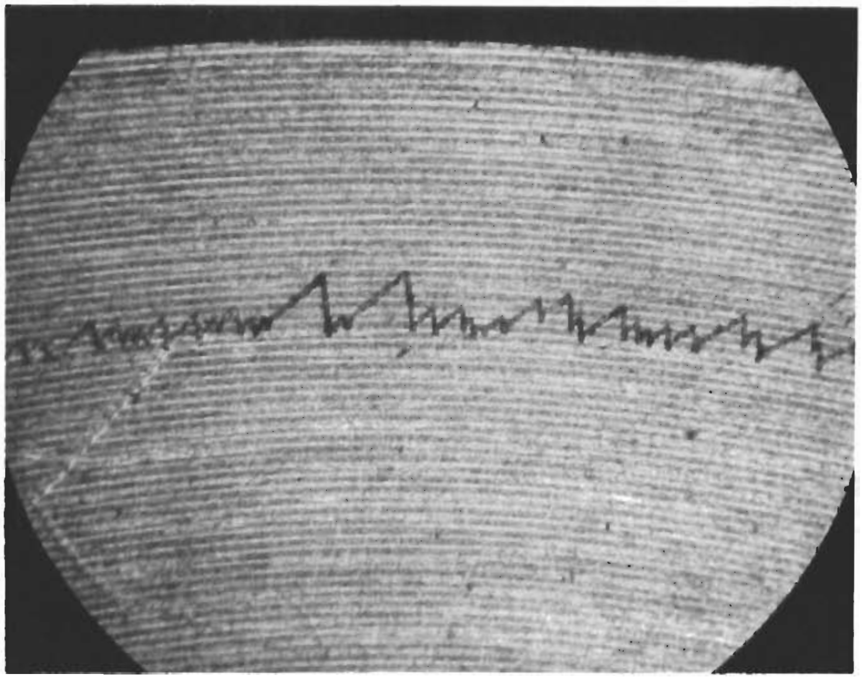

Figure 17. Photomicrograph Of An Unpolished Disc

## 4. DATA CORRELATION

The main effort of correlating scratch gage data against electric gage data was centered around Flight No. 5 of the flight test program. The data comparison was performed mainly on a point-by-point basis.

Flight No. 5 consisted of the maneuvers shown in Table I in the order listed. The maneuvers caused various loadings ranging from zero g to positive 5.5 g's. Although all strain values were read from the oscillograph output for every maneuver, only the values for a few certain individual ones, typical of the rest, are presented. The variation of strain between gages Nos. 16 and 17, was very

## TABLE I

## FLIGHT NUMBER 5 —MANEUVERS

- Taxi
- Take-off
- Split S
- Cuban 8
- Barrel-roll
- Cloverleaf
- Immelmann
- Loop
- Aileron roll
- Power on and secondary stalls
- Recovery from vertical and inverted flight
- Recovery from high-speed dive
- Slow flight
- T. P. stalls
- Left spin
- Right spin
- Maximum performance climbing turn
- Lazy 8
- Single-engine landing touch and go
- Normal landing

small; therefore, only one of the gages, No. 16, was used for reference purposes. The values recorded by No. 16 along with the corresponding scratch gage readings for the same load occurrences are shown in Table II (A & B). (Table II will be explained in greater detail in this section.)

To convert the recorded scratch to an actual strain value, the scratch length must be divided by the effective spanning length of the gage. This length is somewhat arbitrary due to the adhesive width. We have chosen the effective length to be the distance between the centroids of the adhesive area. (B, Figure 18). If other choices, i.e., A, Figure 18, are made, variations of 6% may result for the 6-inch gage.

The first set of scratch gage readings, Table II-A, was calculated using a spanning length of 5.840 inches; the second set, Table II-B, was calculated using a spanning length of 6.190 inches, the total of which was the inside dimension (5.840 inches) plus one half of the epoxy glue strip on each end. This change in length affected the readings by approximately 6%. This indicates that additional tests should be conducted to resolve uncertainties concerning this

## TABLE II

## COMPARISON OF SCRATCH STRAIN GAGE READINGS TO ELECTRICAL STRAIN GAGE READINGS

| Maneuver | A | | | B | | |
|---|---|---|---|---|---|---|
| | L = 5.84 | | | L = 6.19 | | |
| | Electric | Scratch | Δ | Electric | Scratch | Δ |
| Cuban -8 | 530 | 590 | 60 | 530 | 560 | 30 |
| | 1340 | 1400 | 60 | 1340 | 1320 | -20 |
| | 490 | 590 | 100 | 490 | 560 | 70 |
| | 1220 | 1360 | 140 | 1220 | 1290 | 70 |
| | 300 | 410 | 110 | 300 | 380 | 80 |
| | 1060 | 1180 | 120 | 1060 | 1110 | 50 |
| Barrel Roll | 1190 | 1280 | 90 | 1190 | 1210 | 20 |
| | 550 | 680 | 130 | 550 | 640 | 90 |
| | 1550 | 1640 | 90 | 1550 | 1550 | 0 |
| | 710 | 730 | 20 | 710 | 690 | -20 |
| Immelmann | 1390 | 1470 | 80 | 1390 | 1380 | -10 |
| | 290 | 420 | 130 | 290 | 400 | 110 |
| | 940 | 1060 | 120 | 940 | 1000 | 60 |
| Recovery from Inverted Flight | 1320 | 1430 | 110 | 1320 | 1350 | 30 |
| | -30 | 50 | 80 | -30 | 40 | 70 |
| | 690 | 780 | 90 | 690 | 740 | 50 |

length. Table II is a small random sample presentation of all the strain readings recorded.

The scratch gage readings were consistently higher than the electrical resistance gage readings. This was contrary to engineering intuition since the bending moment of the spar should increase as it proceeds inboard and the electric gage was 5 inches farther inboard than the center of the scratch gage. A spanwise strain gradient for the spar was obtained in an attempt to explain the increased strain readings. Electrical resistance gages at stations 54.28, 54.91, 56.25, and 59.10 were read for the Barrel Roll maneuver in Flight No. 5.

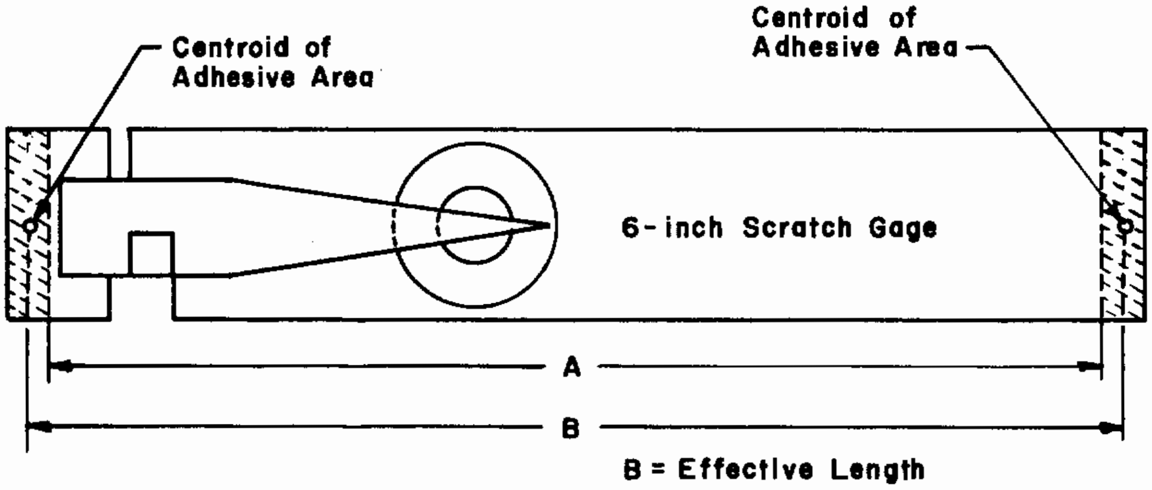

Figure 18. Illustration Of Effective Spanning Length Of Gage

These values have been plotted along with the scratch gage readings, (Figure 19), but were of little help since no evidence was given of the strain values which existed farther outboard of the scratch gage. A second plot was made from values which were recorded by electric gages from various positive g flight maneuvers conducted previously by the Cessna Aircraft Co. (Figure 20). This plot did verify a definite increase in strain at station 64.00. Two maneuvers were used to show a positive trend.

It must be remembered that the scratch gage records an extension or contraction of a preset length; in this case, 6 inches. Therefore, the gage records, not a unit strain, but an average strain value computed over the spanning length. Consequently, a 6-inch scratch gage would not be a recommended recording device in an area where the strain varies considerably such as stations 54 to 59 (Figure 20).

The scratch strain record of Flight No. 5 on the 3-inch gage was also read and compared to the output of the electric gage, No. 16, which was on the other wing. A photomicrograph of the recording on the brass disc is shown in Figure 21. The trace was easily read using the calibrated microscope method, which has a reading precision of less than $50\mu\epsilon$ . The spanning length of the gage, 3.24 inches, was measured in between the centroids of the adhesive areas

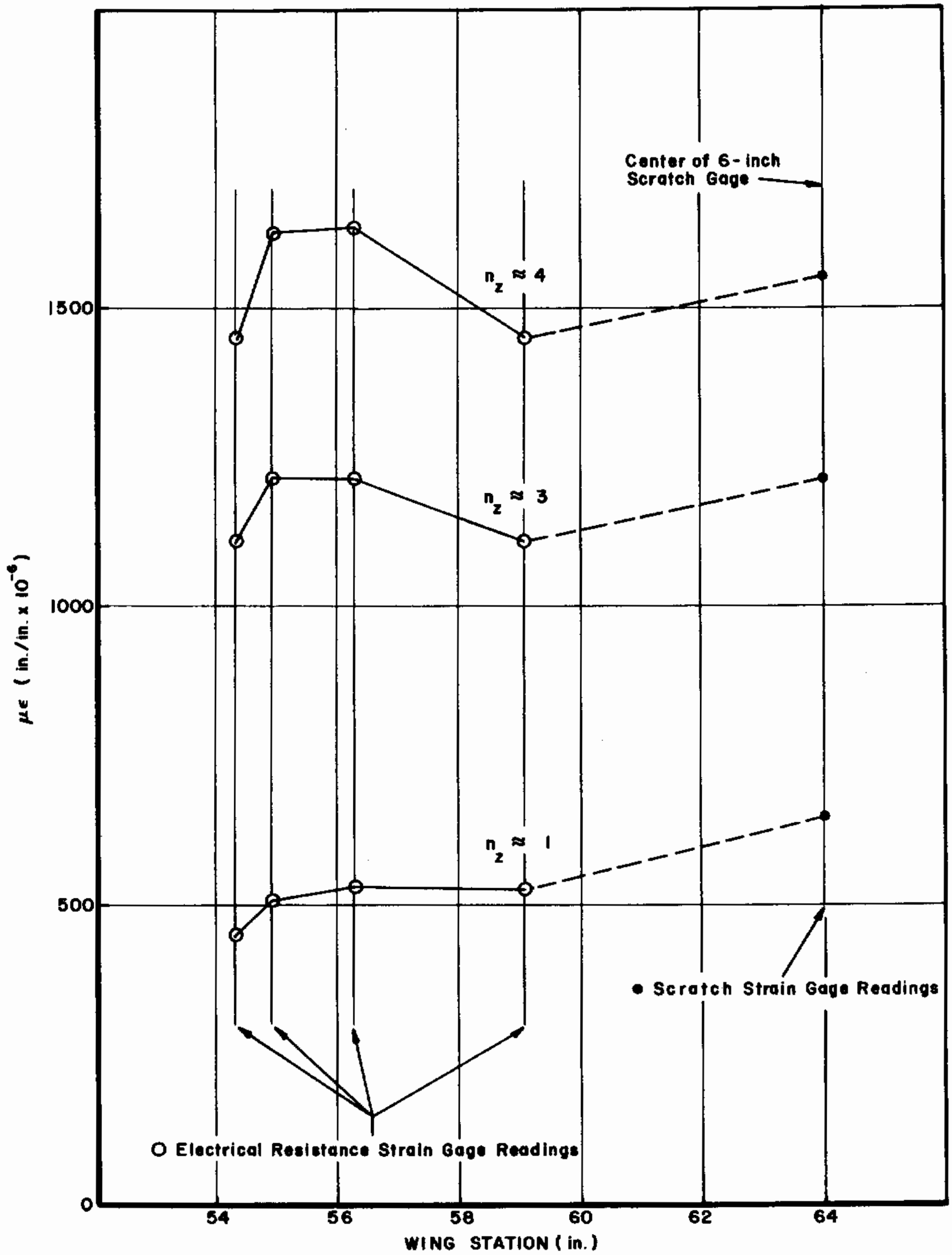

Figure 19. Strain Gradients At Various Times During A Barrell-Roll Maneuver

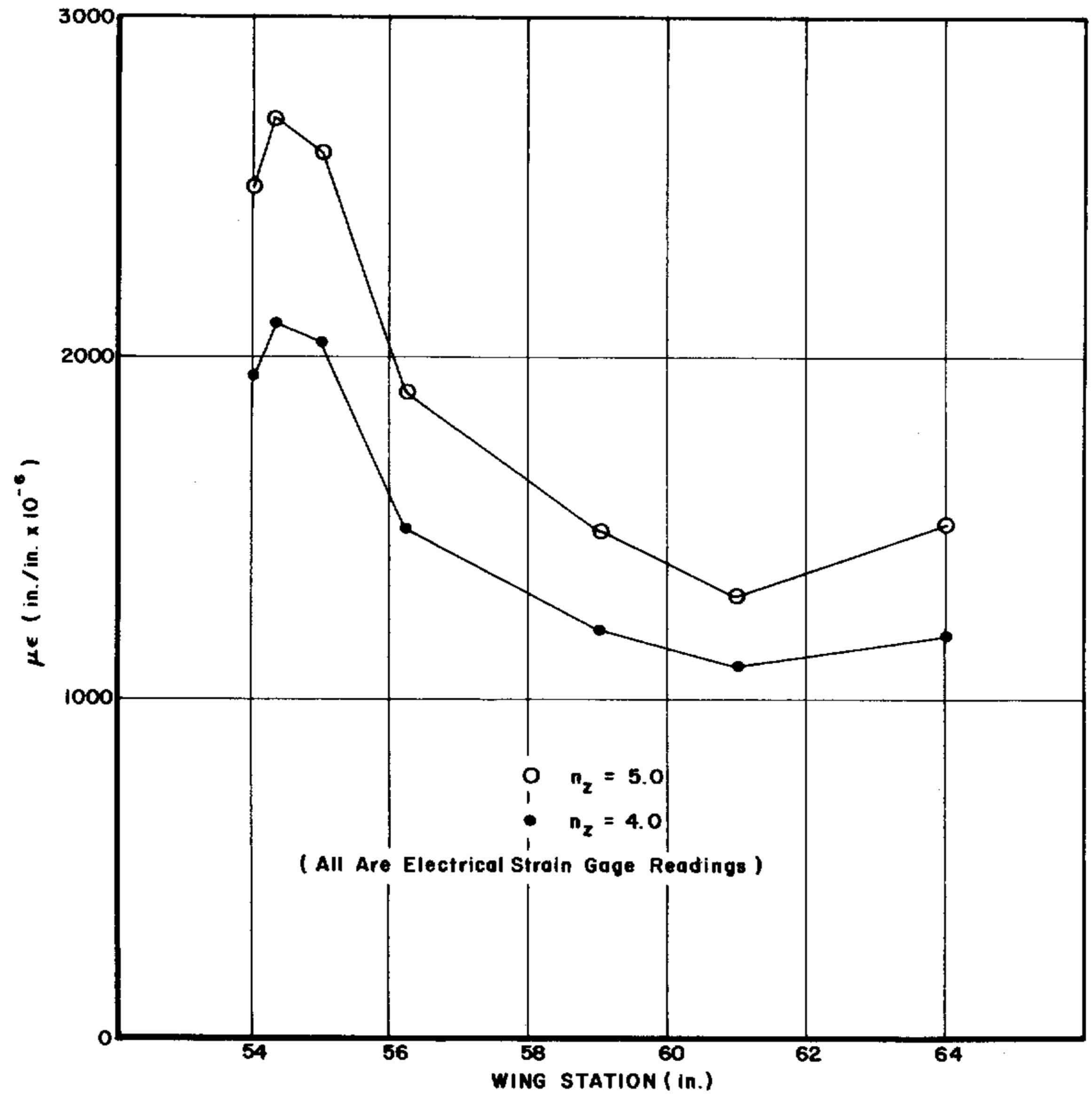

Figure 20. Spanwise Strain Distribution During A Positive Maneuver

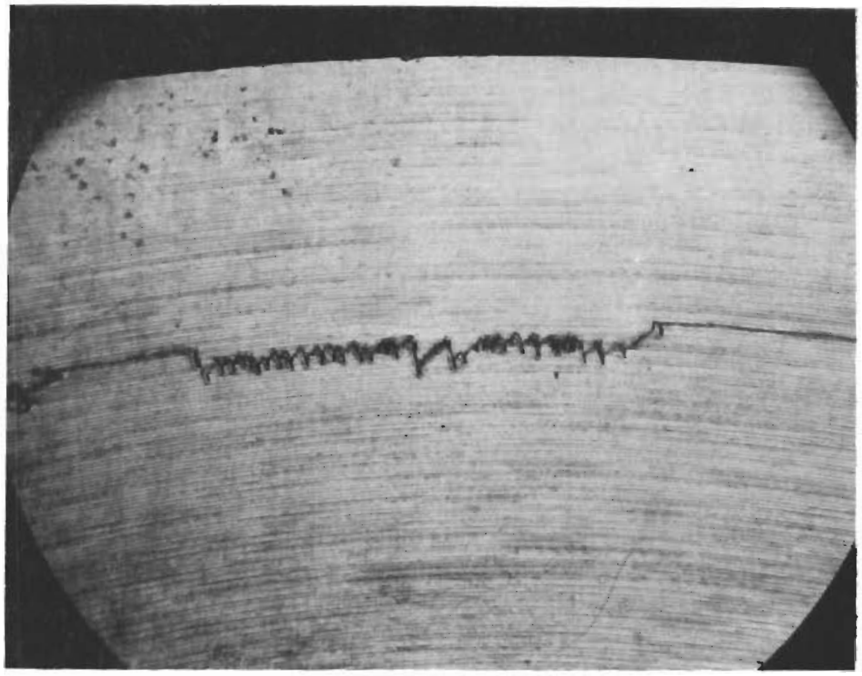

Figure 21. Three-Inch Scratch Gage Strain Record Of Flight No. 5

(B, Figure 18). The correlation between the scratch readings and electric readings was very erratic as seen in Table III. This deviation is due mainly to the fact that the 3-inch scratch gage and electrical resistance gages were on opposite wings which would respond differently to asymmetrical maneuvers.

The accuracy of the 3-inch gage is shown by the correlation of data of a symmetric maneuver (Table IV).

## TABLE III

## MAXIMUM AND MINIMUM STRAIN DATA COMPARISON BETWEEN 3-INCH SCRATCH GAGE AND ELECTRICAL RESISTANCE GAGE NO. 16 FOR ASYMMETRIC MANEUVERS

| Electric Gage $\mu\epsilon$ | Scratch Gage $\mu\epsilon$ | $\Delta$ $\mu\epsilon$ |
|---|---|---|
| 1440 | 1135 | -305 |
| 230 | 335 | 105 |
| 1410 | 1320 | -90 |
| 180 | 305 | 125 |
| 1220 | 1320 | 100 |
| 670 | 305 | -365 |
| 1050 | 1040 | − 10 |

$\Delta \equiv$ Scratch Minus Electric

## TABLE IV

## MAXIMUM AND MINIMUM STRAIN DATA CORRELATION BETWEEN 3-INCH SCRATCH GAGE AND ELECTRICAL RESISTANCE GAGE NO. 16 FOR A SYMMETRIC MANEUVER

| Electric Gage $\mu\epsilon$ | Scratch Gage $\mu\epsilon$ | $\Delta$ $\mu\epsilon$ |
|---|---|---|
| 1380 | 1330 | -50 |
| 540 | 520 | -20 |
| 1450 | 1290 | -160 |
| 180 | 150 | -30 |
| 1320 | 1210 | -110 |
| − 30 | − 30 | 0 |

$\Delta \equiv$ Scratch Minus Electric

## SECTION V

## APPLICATIONS

In service, the most effective use of a device such as the Prewitt Scratch Gage would be in a tail number fatigue damage monitoring program. In this role, individual aircraft would be equipped with one or more strategically located gages installed to monitor strain continuously. With correct placement, information from numerous flights could be contained on one target since disc capacity is merely a function of the total number and magnitude of strain occurrences sensed by the gage. By taking advantage of prior system operational usage of the scratch gage concerning the most damaging mission segments and strain values, the amount of data to be stored on one single target could be greatly increased.

Automatic disc interrogation and data retrieval on a regularly scheduled basis is required for an efficient and economical damage monitoring system. In its ultimate sense, such a system would, in a minimum number of operations, transpose target information into an increment of fatigue damage sustained during the operational time period contained on the disc. Figure 22 is a schematic of such a system.

The basic steps of this type of system would be the following.

1. Instrumentation of fighter and/or trainer aircraft, preferably on a fleet wide basis.

2. Electronically and automatically reduce the data contained on the discs by digitizing it using the various counting methods.

3. Tabulate data and code in a format suitable for inclusion as basic input into a computer routine for calculating fatigue damage.

4. Catalog computer output according to individual aircraft tail numbers for future use.

To demonstrate the manner in which the data from a disc must be reduced, the preliminary operations for a percentage damage calculation were made

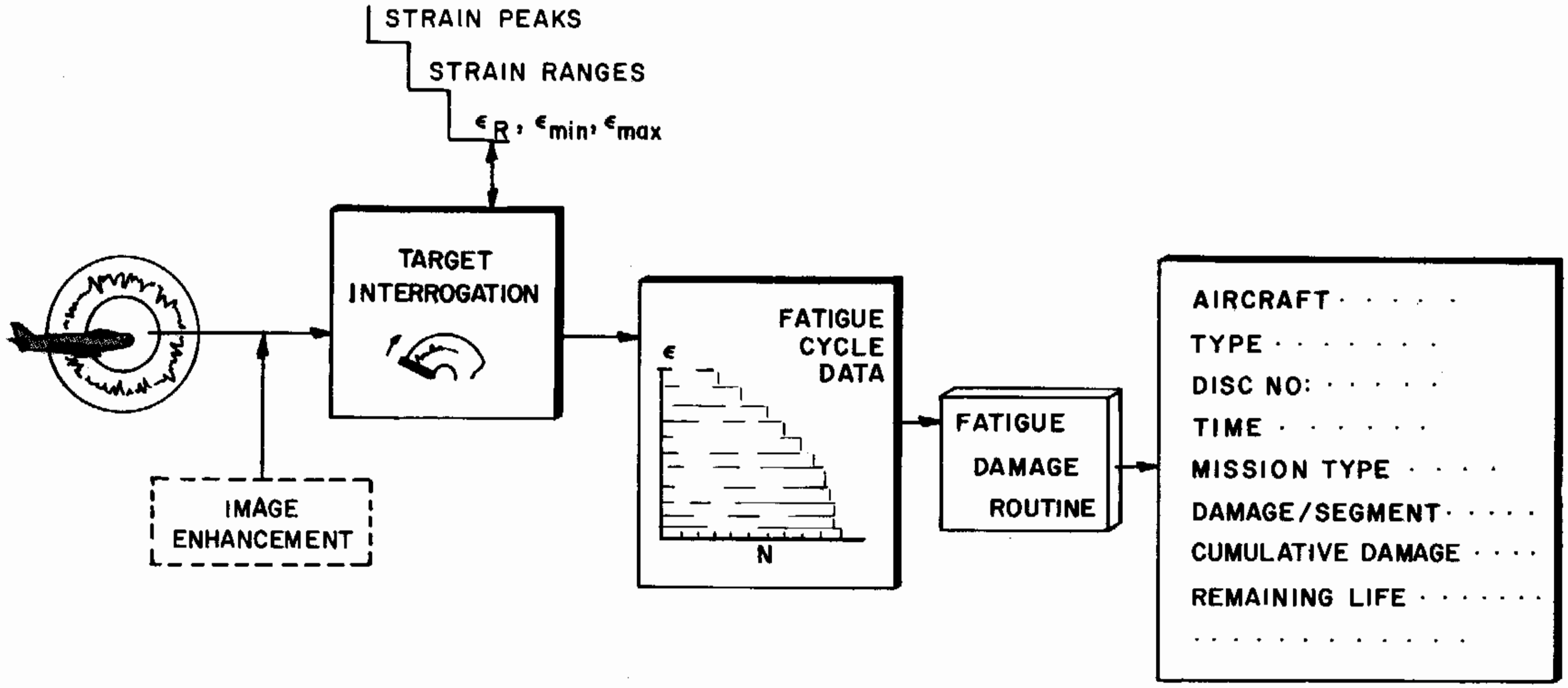

Figure 22. Tail Number Fatigue Life Monitoring System For Fighter Aircraft

using the 3-inch scratch gage, Flight No. 2 recording (Figure 23). Various g load levels (-2, 0, 4, and 6) have been marked on the photograph. The cumulative frequency of occurrence graph (exceedance curve), Figure 24, was made by reading the photomicrograph directly at incremental load levels of 1 g using the level-crossing counting method. This was accomplished using a calibrated eyepiece. From this plot, an occurrence graph, Figure 25, was obtained by substracting the abscissa coordinate of the incremental 1 g load levels of Figure 24. This graph is directly transferred into table form, Table V, to be used in conjunction with previously acquired S-N data. Finally, a standard damage calculation method based on the Miner cumulative damage rule would normally be employed and the percent of total damage is obtained.

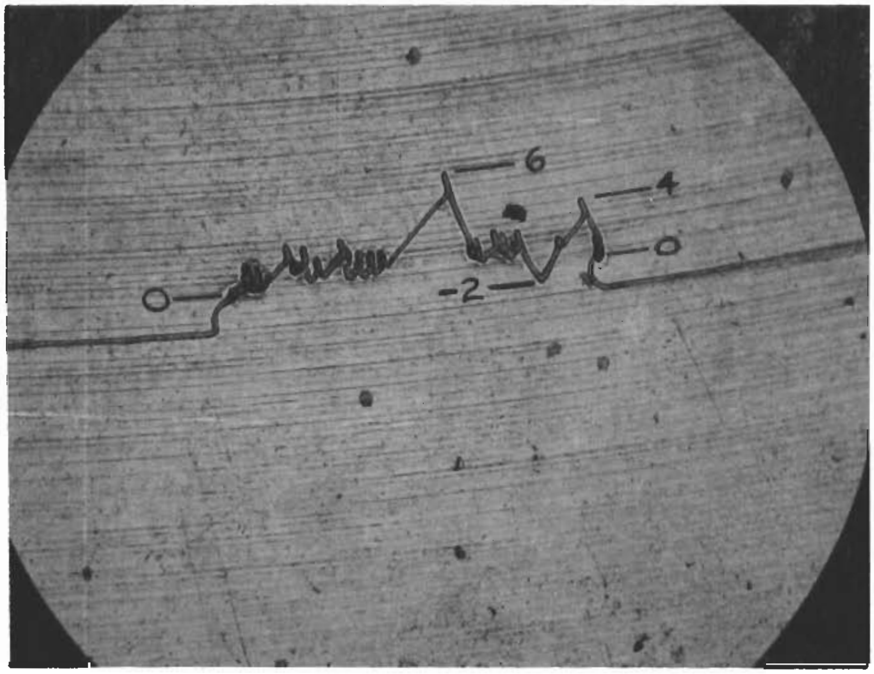

Figure 23. Three-Inch Scratch Strain Gage Record Of Flight No. 2

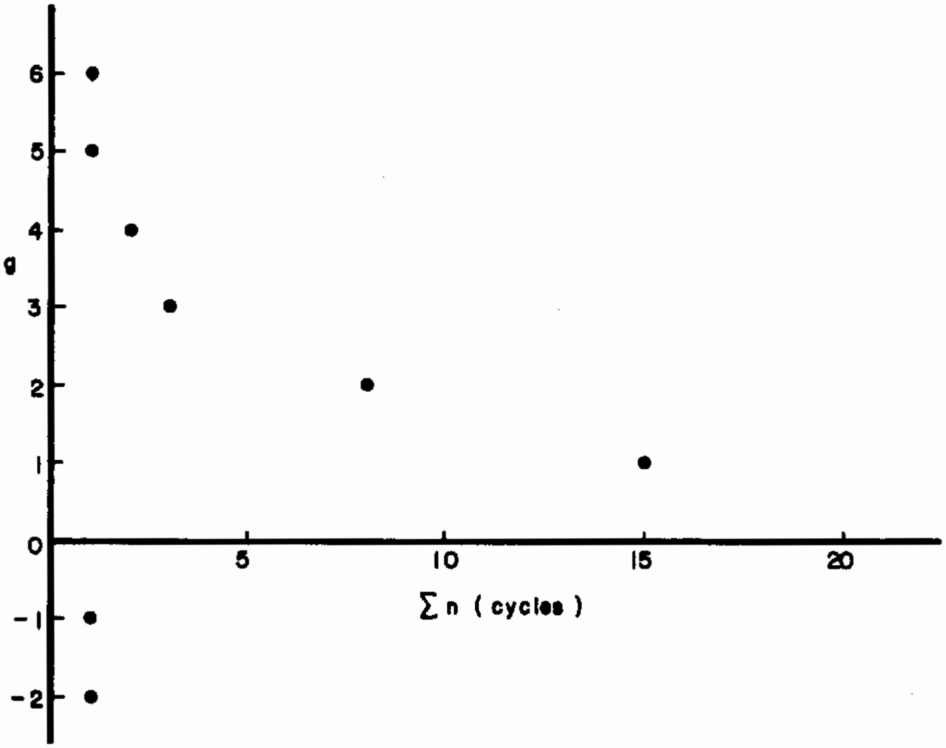

Figure 24. Cumulative Frequency Of Occurrence Of Normal Load Factor

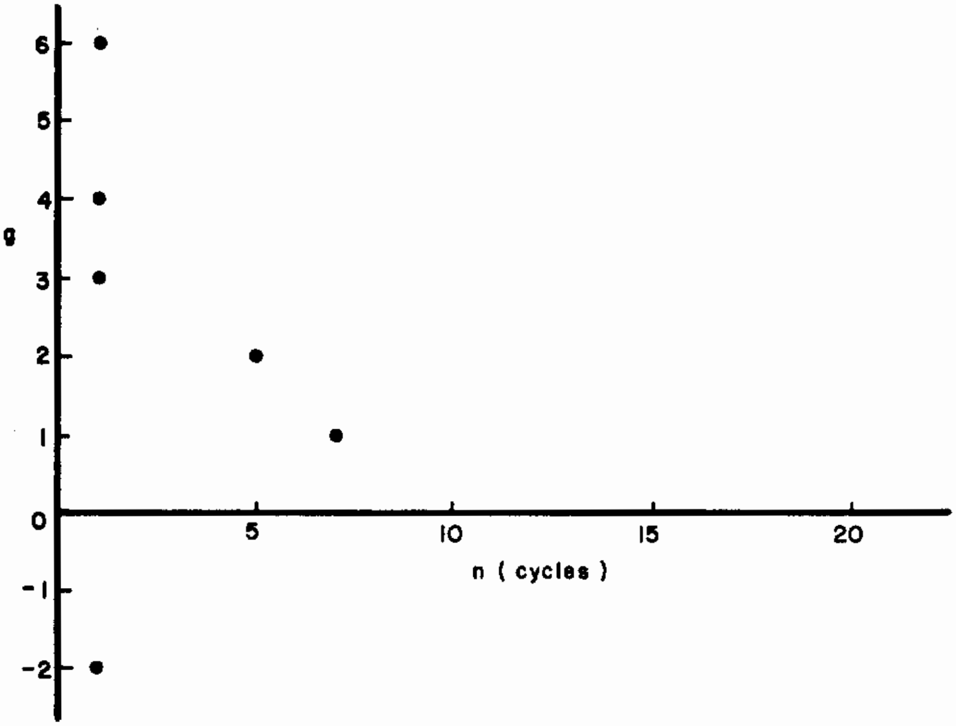

Figure 25. Frequency Of Occurrence Of Normal Load Factor

## TABLE V

## FLIGHT NO. 2 DAMAGE DATA

| g | Cycles | $\sigma_{max}$ (PSI) |
|---|---|---|
| −3 | 0 | −13500 |
| −2 | 1 | −9000 |
| −1 | 0 | −4500 |
| 0 | 0 | 0 |
| 1 | 7 | 4500 |
| 2 | 5 | 9000 |
| 3 | 1 | 13500 |
| 4 | 1 | 18000 |
| 5 | 0 | 22500 |
| 6 | 1 | 27000 |
| 7 | 0 | 31500 |

$\sigma_{min}$ = 1g ≈ 4500 PSI

(g at Gage Location Based on Trim Stress and Measured $\Delta\epsilon$ )

## SECTION VI

## CONCLUSIONS

The major results and significant observations of the scratch strain gage as installed in the locations previously described on the T-37B can be summarized as follows:

1. The random sampling of the test results presented herein indicates that the 3-inch gage is capable of recording maximum and minimum strain values produced by typical fighter aircraft maneuvers above 1.5 $\Delta$g; (0.5 $\Delta$g for 6-inch gage).

2. All damaging strain range cycles can be detected and recorded with a proper choice of gage length. ($L \geq 0.002/\Delta\epsilon$ (Reference 2).

3. As a result of this study the gage spanning length is taken as the distance between the centroids of the glue strips (B, Figure 17). Further testing, however, would be appropriate.

4. Individual strain readings as large as 2400 $\mu\epsilon$ were recorded. Based on the results of Reference 2, maximum recording limit values of 5000 $\mu\epsilon$ (tension) and 4000 $\mu\epsilon$ (compression) were possible with the 6-inch gage. The 3-inch gage had twice this capacity.

5. If the recordings of individual small maneuver (less than 1.5 $\Delta$g) and gust strains are not necessary for damage calculations, the 3-inch gage would be adequate and would allow a minimum of 30 hours flight time between disc replacement. If the recording of the small loads is necessary, a 6-inch gage would be required and the flight time recording capacity would be reduced to approximately seven flight hours per one revolution of the brass disc.

6. Laboratory tests have been conducted and have shown that the strain recording capacity of the gage is not affected by variable frequency strain cyclic loading from 0 cps to 4 cps.

7. The results and findings of the flight test presented in this report suggest that the scratch strain gage is an effective strain sensor and with future developmental testing could likely be used in a program of aircraft tail number fatigue damage monitoring.

# APPENDIX

## GAGE DESCRIPTION

The Prewitt Scratch Strain Gage is a self-contained mechanical extensometer capable of measuring and recording total deformation (and thus average strain) over the effective installed gage length of the member to which it is attached.

As indicated in Figure 26, the gage consists of two steel base plates (1) and (2), with (1) containing a recording stylus, and (2) the brass recording disc. Physical attachment of the gage assembly to the structure is achieved by either bonding, clamping, or screwing the ends of each base plate.

The outer periphery of the disc is grooved so as to accommodate two rollers (A and B, Figure 26) and encased steel wire brushes (C and D, Figure 26) used to hold the disc in place.

As the structure is strained, the two base plates move relative to each other, causing the stylus to scratch the disc and record the total movement. Automatic rotation of the disc occurs under cyclic straining allowing separation of each strain excursion. This counterclockwise rotation is accomplished during gage contraction by the tangential force of the longer brush, D on the circumference of the disc. The shorter brush, C, is used merely to prevent reverse rotation.

Electrical resistance strain gages (E and F, Figure 26) were also mounted to monitor the strain application.

The gage gap, (the spacing between the two base plates of the gage, X, Figure 26) is critical since it controls the rotation capabilities of the disc at various strain levels.

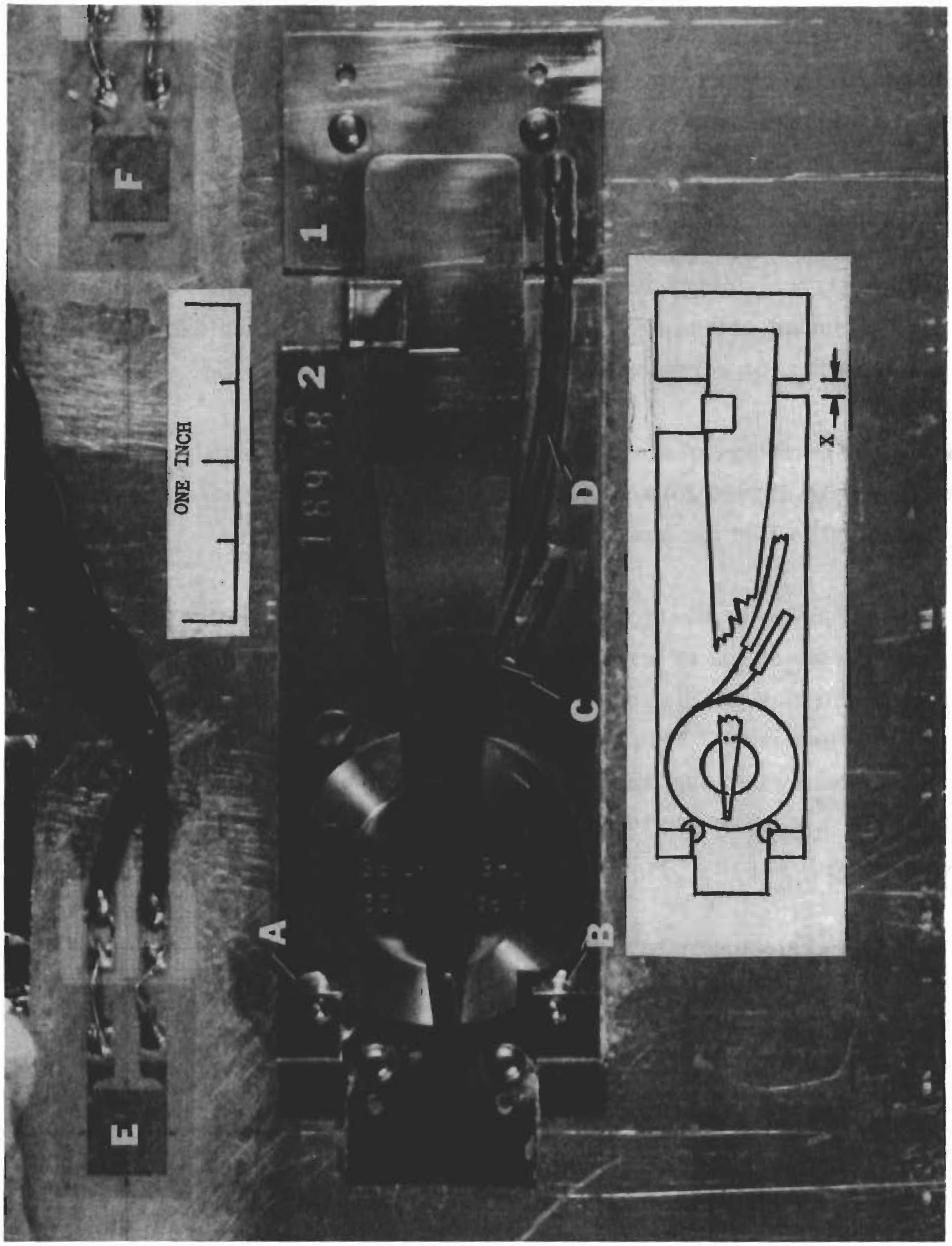

Figure 26. Three-Inch Prewitt Scratch Gage

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13. ABSTRACT

This report presents flight test results on the operation of the Prewitt Scratch Strain Gage. The program involved the use of a T-37B, which was previously instrumented for use as a flight loads survey aircraft. Three scratch gages were installed on the aircraft.

The flight program included individual high and low g maneuvers and also maneuvers taken from the Air Training Command flight syllabus. Data correlation between the electrical resistance gages and the scratch gages was accomplished.

The results indicate that the scratch strain gage is a feasible and reliable means of recording strain cycles of a character and magnitude found in a fighter aircraft structure.

Automated data reduction techniques and system applications of the gage are discussed.

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