| | NAME | DATE | LOCKHEED — GEORGIA COMPANY A DIVISION OF LOCKHEED AIRCRAFT CORP. | PAGE | TEMP. | PERM. 4.1 |
|---|---|---|---|---|---|---|
| PREPARED | R. Birdseye | 1-30-78 | TITLE FY 1977 C-130 SERVICE LIFE ANALYSIS SERVICE LIFE SUMMARY | MODEL | C-130 | |
| CHECKED | S. K. Brown | 1-30-78 | | REPORT NO. | LG78ER0020 Vol III | |
| APPROVED | E. S. Hendrix | 1-30-78 | | | | |

## 4.0 STRUCTURAL ANALYSIS LOCATIONS

The C-130 aircraft is divided into four major structural components for this analysis. The four components are the center wing, outer wing, fuselage, and empennage. The major structural components are shown in Figure 4.1. The analysis locations considered for each of the four major components consisted of primary structure. The nose landing gear, main landing gear, external fuel tank pylon, engine nacelles, and control surfaces were not considered in this analysis.

### SUMMARY OF ANALYSIS LOCATIONS BY MAJOR COMPONENT AND SERIES

| | C-130A | C-130B | C-130E | C-130H* |
|---|---|---|---|---|
| Center Wing | 7 | 5 | 5 | 5 |
| Outer Wing | 8 | 8 | 10 | 10 |
| Fuselage | 34 | 33 | 33 | 33 |
| Empennage | 2 | 2 | 2 | 1 |

## 4.1 CENTER WING

The first major component considered in the service life analysis is the center wing. There are currently two structural configurations of the center wing in the Air Force C-130 fleet. These configurations are the center wing on the C-130A and C-130B/E/H aircraft. Three main areas of the center wing are considered in this analysis. These areas constitute the major discontinuities in the center wing. Figure 4.2 shows the general analysis areas on the center wing. Figure 4.3 lists the specific locations analyzed on the center wing structure along with a description of each location and to which series type the location is applicable. Figures 4.4 through 4.8 show a detailed picture of each analysis location and the general area of the location on the center wing.

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MARIETTA, GEORGIA

REPORT NO. LG78ER0020 VOL. III
MODEL C-130
PAGE 4.2

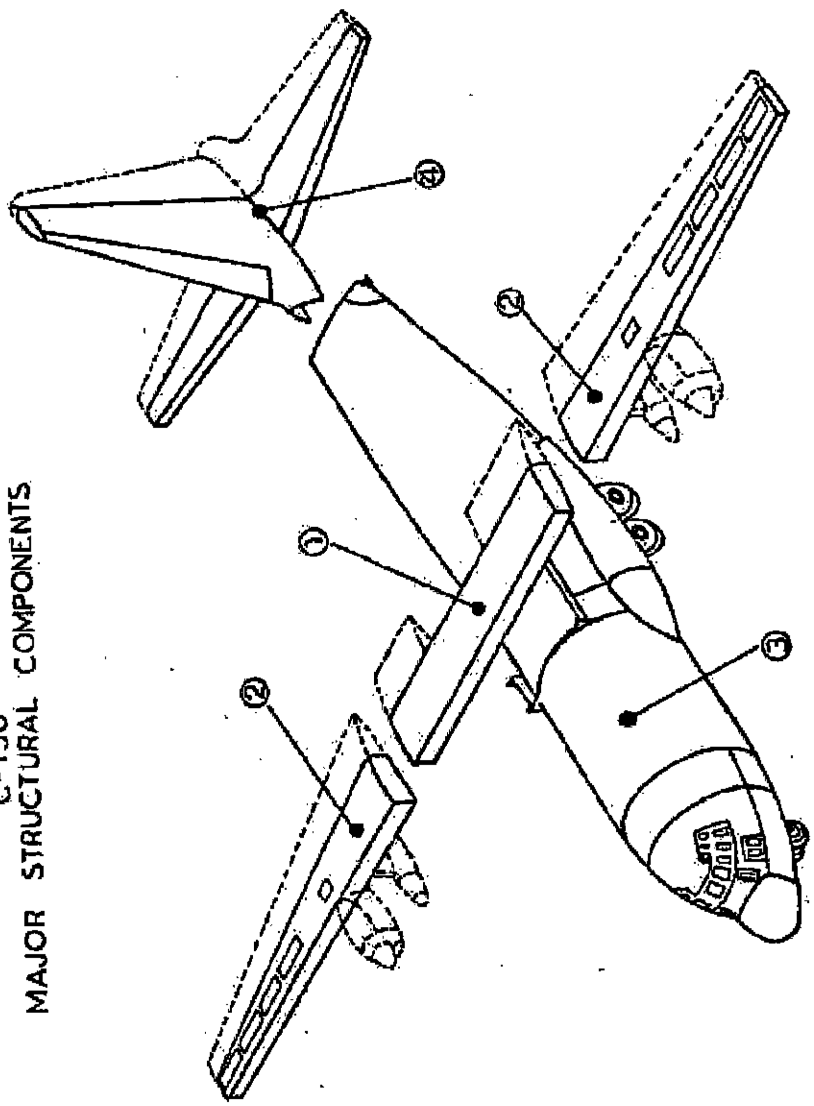


FIGURE 4.1
C-130
MAJOR STRUCTURAL COMPONENTS

① CENTER WING
② OUTER WING
③ FUSELAGE
④ EMPENNAGE

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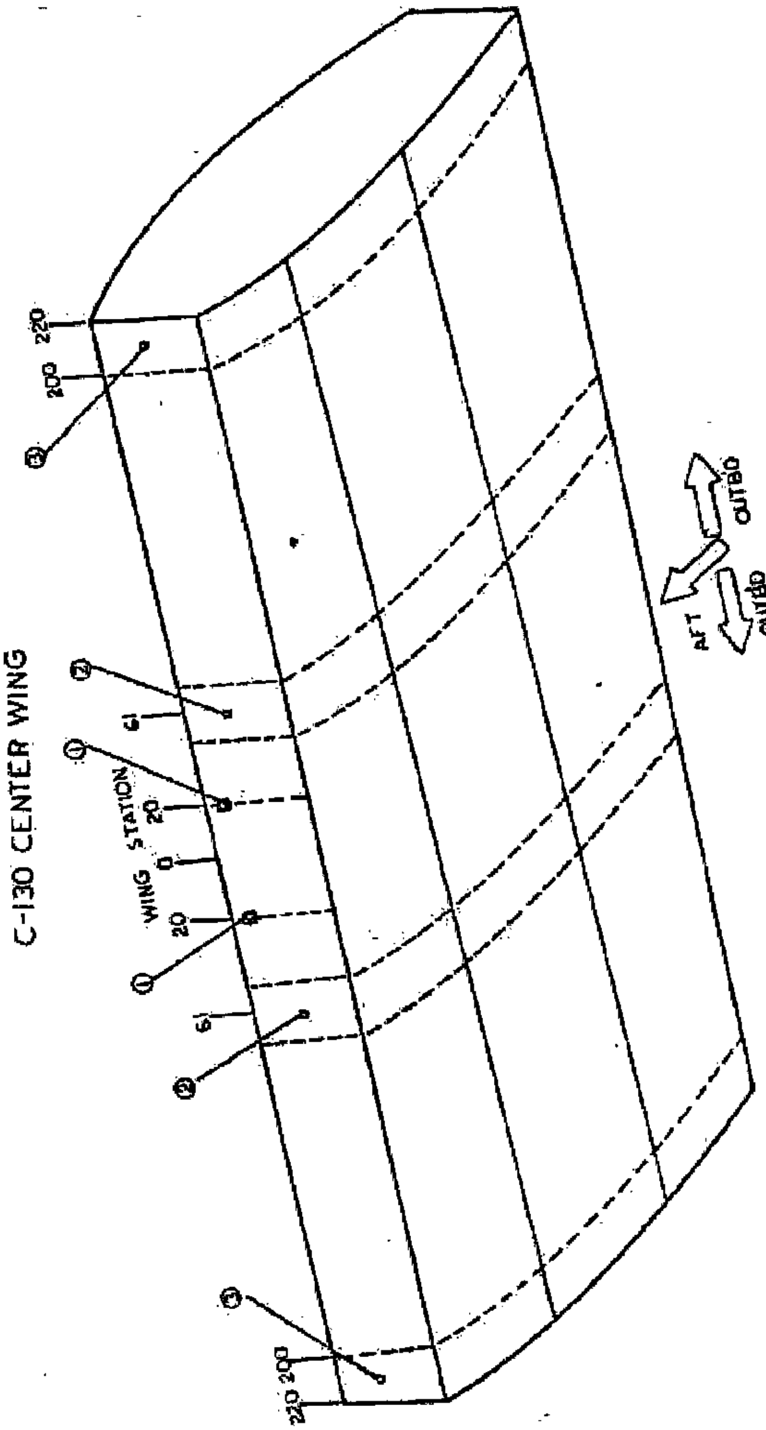
REPORT NO. LG78ER0020 Vol. III
MODEL C-130
PAGE 4.3

FIGURE 4.2
GENERAL LOCATIONS




① FUSELAGE LONGERON CARRY THRU—1 Location
② FUSELAGE-WING JOINT—4 Locations
③ OUTER WING-CENTER WING JOINT — 4 Locations

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|---|---|---|---|---|---|---|
| PREPARED | R. Birdseye | 1-30-78 | TITLE FY 1977 | MODEL C-130 | | |
| CHECKED | S. K. Brown | 1-30-78 | C-130 SERVICE LIFE ANALYSIS | LG78ER0020 | | |
| APPROVED | E. S. Hendrix | 1-30-78 | SERVICE LIFE SUMMARY | REPORT NO. Vol III | | |

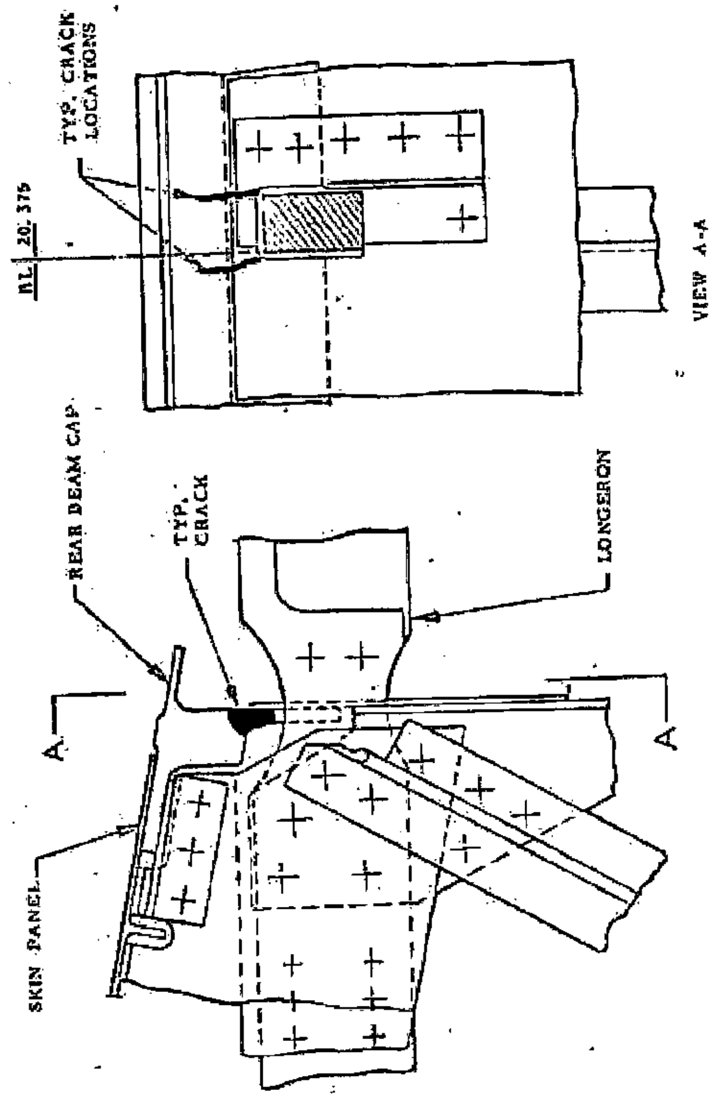
FIGURE 4.3

C-130 CENTER WING ANALYSIS LOCATIONS

| Station | Location Description | Area | Applicability | Fig. No. |
|---|---|---|---|---|
| CWS 20 | Upper Aft Spar Cap | 1 | A | 4.4 |
| CWS 58-61 | Upper Aft Spar Cap | 2 | All | 4.5 |
| CWS 58-61 | Upper Forward Spar Cap | 2 | All | 4.5 |
| CWS 61 | Lower Surface Skin Panels | 2 | All | 4.6 |
| CWS 79 | Lower Aft Spar Cap and Beam Web | 2 | B & Up | 4.6 |
| CWS 180 | Lower Surface Skin Panels | 3 | A | 4.7 |
| CWS 192 | Upper Skin at Access Door | 3 | A | 4.7 |
| CWS 214 | Upper Stringers No. 2 & 5 | 3 | A | 4.8 |
| CWS 214 | Lower Surface Skin Panels | 3 | B & Up | 4.8 |

FIGURE 4.4
CENTER WING ANALYSIS LOCATIONS

C-130A UPPER REAR BEAM CAP CRACKING



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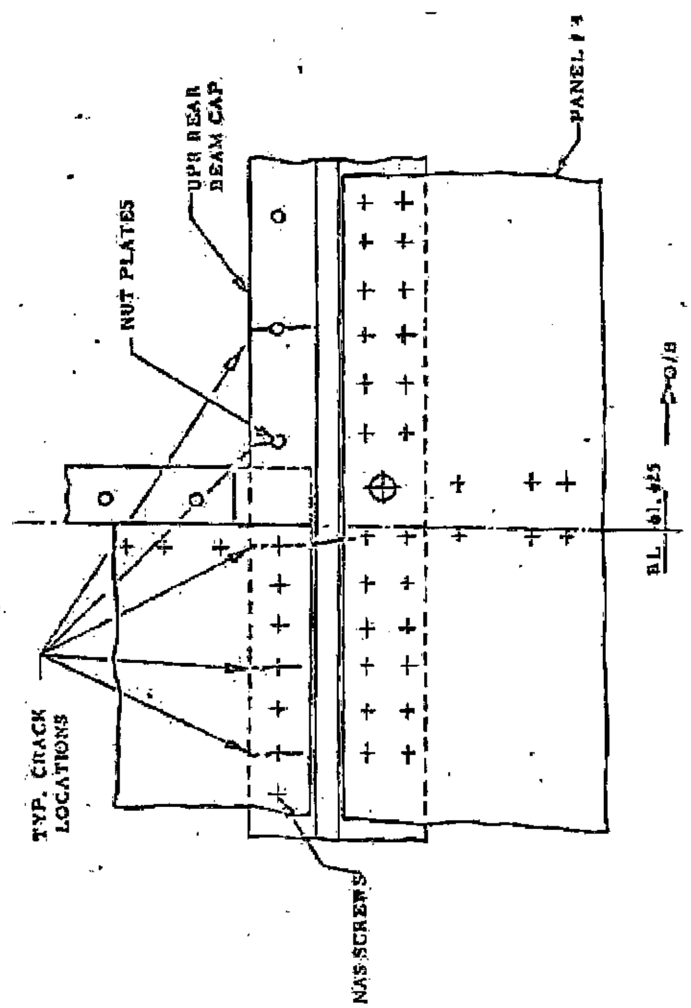
MARIETTA, GEORGIA

REPORT NO. LG78ER0020 Vol. III
MODEL C-130
PAGE 4.6

# FIGURE 4.5
# CENTER WING ANAYSIS LOCATIONS

C-130A UPPER REAR BEAM CAP CRACKING
(FRONT BEAM SIMILAR)



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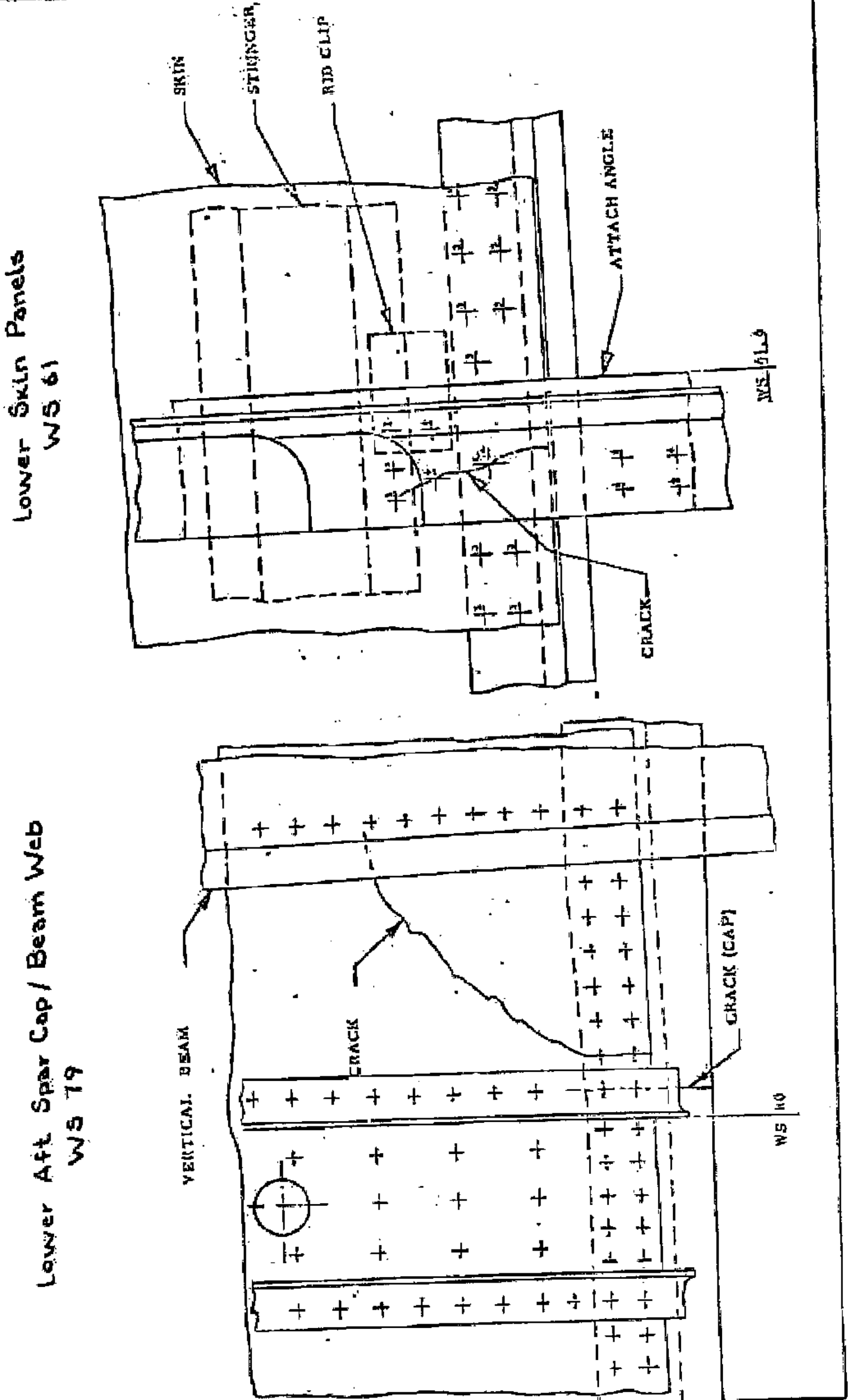
MARIETTA, GEORGIA

REPORT NO. LG78ER0020 Vol. III
MODEL C-130
PAGE 4.7

FIGURE 4.6
CENTER WING ANALYSIS LOCATIONS



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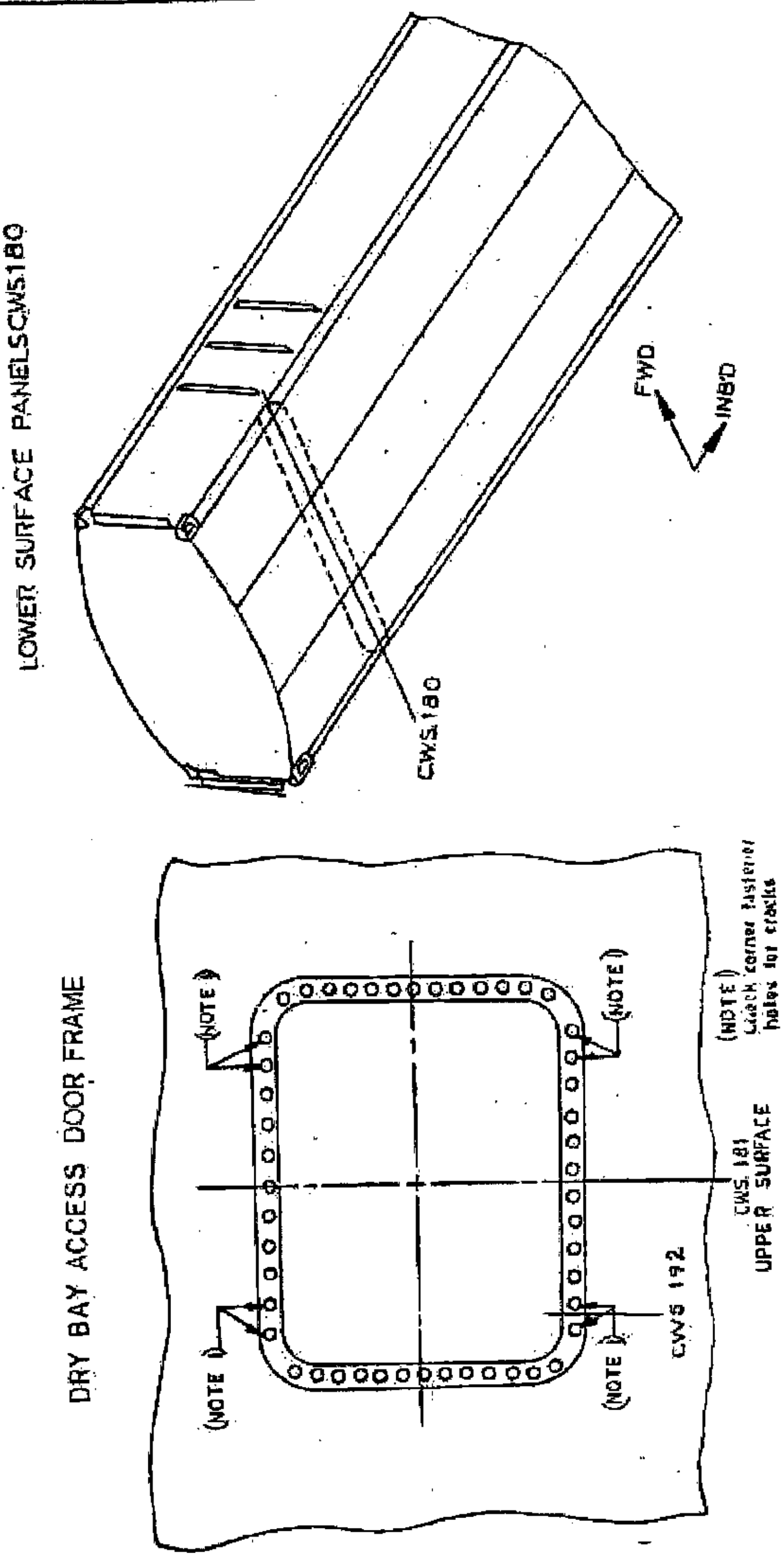
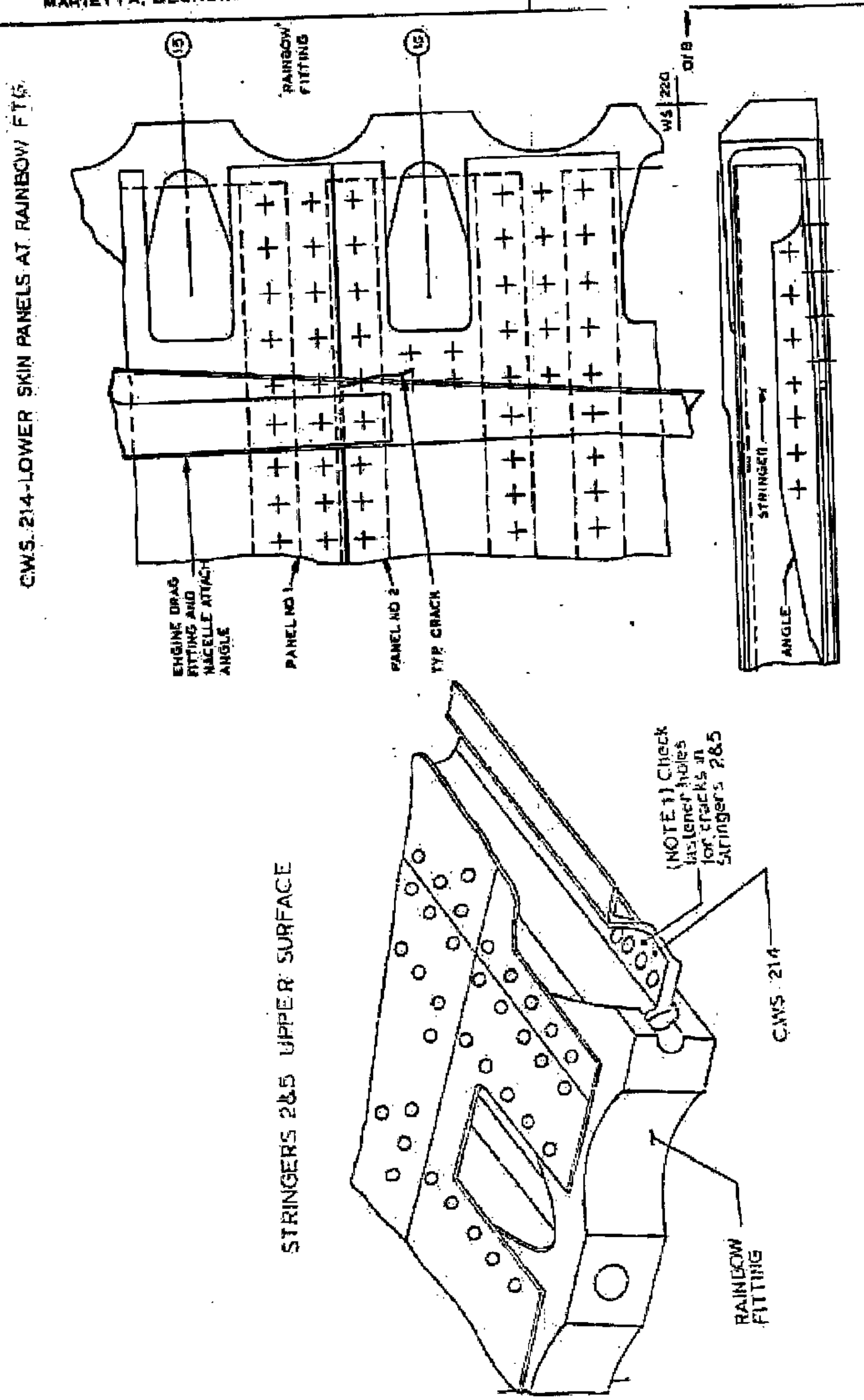
REPORT NO. LG78ER0020 Vol. III
MODEL C-130
PAGE 4.8

FIGURE 4.7
CENTER WING ANALYSIS LOCATIONS



# FIGURE 4.8
# CENTER WING ANALYSIS LOCATIONS



5.4. SERVICE LIFE DERIVATION

5.4.1 C-130A

Center Wing

The center wing on the C-130A series aircraft has seven (7) locations that were considered in this analysis. These seven locations are located on four structural parts on the center wing (the upper aft spar cap, the upper forward spar cap, the upper surface skin panels, and the lower surface skin panels). The equations① used to sum the total number of cracks expected on each of these structural parts are as follows:

① Upper forward spar cap = (CWS 61)

② Upper aft spar cap = (CWS 20) + .464 (CWS 61)

③ Upper skin panels = (CWS 192) + .500 (CWS 214)

④ Lower skin panels = (CWS 180) + .500 (CWS 61)

The results of these summations are shown in Figure 5.6 for each of the four structural parts. The combined average for the center wing is shown also. From this curve the Service Life Endurance Point and the Structural Action Point are defined as 19,384 and 11,910 flight hours respectively.

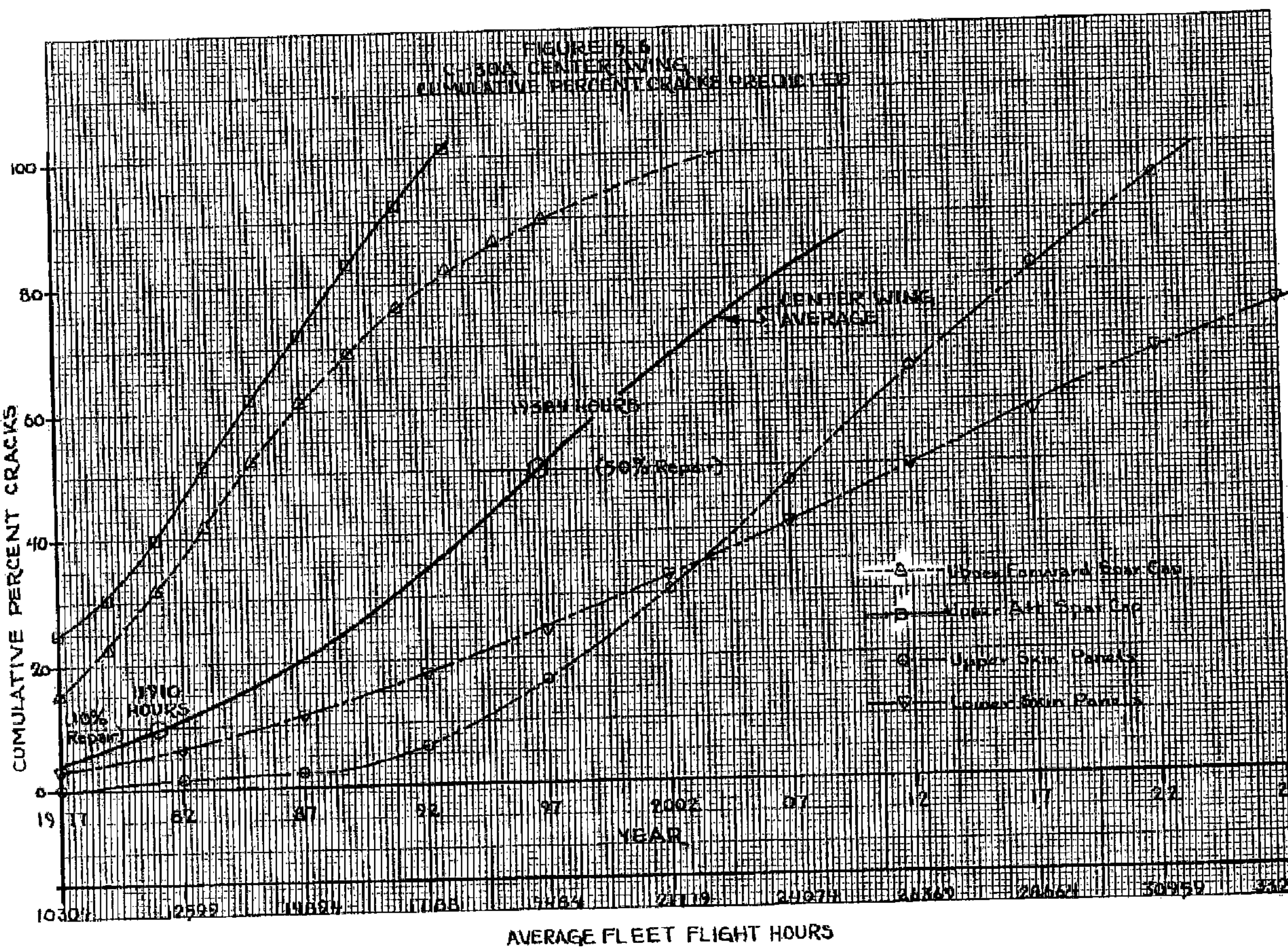
Outer Wing

The outer wing on the C-130A series aircraft has nine locations that were considered in this analysis. These are located on three structural components on the outer wing, the upper surface skin panels, the lower surface skin panels, and the lower forward spar cap. The equations① used to sum the total number of cracks predicted on each of the structural components are as follows:

① Equations derived using in-service crack experience (Ref. pg 5.16)

G.A. FORM 362D-1

K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1323




LG78ER0020 Vol. III
Page 5.20

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|---|---|---|---|---|---|---|
| PREPARED | R. Birdseye | 9-1-78 | TITLE FY 1977 C-130 SERVICE LIFE ANALYSIS SERVICE LIFE SUMMARY | MODEL C-130 | | |
| CHECKED | S.K. Brown | 9-1-78 | | LG78ER0020 REPORT NO. Vol III | | |
| APPROVED | E.S. Hendrix | 9-1-78 | | | | |

## B3.0 MODEL C-130A CENTER WING LOWER SURFACE WS 61

During hydrostatic fatigue test of the model C-130A fuselage, the catastrophic failure of the wing occurred at 13,203 cycles at an applied wing upbending moment of $16.0 \times 10^6$ in.lb. at WS 61 (16.0/25.6 = 62.5 percent of limit design moment). The lower surface of the center wing failed in tension at BL 59 and the failure extended from FS 517R to FS 597R (from front beam to rear beam). (See Figures 4.360 and 4.361, ER 1735).

The inspection of the failed wing showed a large number of fatigue crack indications in the vicinity of the lower surface at WS 61 left and 61 right. The largest concentration of cracks were in the lower surface skin panels adjacent to the front and rear beam.

The USAF C-130A fleet is approaching an average of 11,000 flight hours with a high time aircraft having 16,000 flight hours. Analysis shows that at ultimate load the calculated tension stress at WS 61 lower surface is 54.3 ksi (54.3/1.5 = 36.2 ksi at limit load). In view of this relatively high operating stress level and accumulated flight hours in C-130A fleet, it is recommended that the C-130A fleet be inspected for cracks in the vicinity of WS 61 center wing lower surface. The recommended inspection intervals are:

Initial: 12,000
Recurring: 2,500

Inspection procedures for this area are shown as inspection items CW2 thru CW4 in Section IV of TO 1C-130A-36. (Technical Manual Non Destructive Inspection Procedures USAF Series C-130A Airplanes). This procedure suggests that in order to maintain the integrity of the wing, it must be supported in neutral stress position prior to removal of attaching bolts. In order to enhance the chances of detection of existence of a crack, it is recommended that the wing be jacked so as to have tension in the lower surface. The jacking procedure to be used for the inspection of the lower surface is shown in TO 1C-130A-3 (Figure 2.3, Change 14, dated 15 Jan 1973). The amount of the required jacking is shown on the following page.

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| PREPARED | R.Birdseye | 9-1-78 | TITLE FY 1977<br>C-130 SERVICE LIFE ANALYSIS<br>SERVICE LIFE SUMMARY | MODEL C-130 | | |
| CHECKED | S.K.Brown | 9-1-78 | | LG78ER0020 | | |
| APPROVED | E.S.Hendrix | 9-1-78 | | REPORT NO. Vol III | | |

B3.0 MODEL C-130A CENTER WING LOWER SURFACE WS 61 (cont'd)

| STRUCTURAL CONFIGURATION | JACKING LOCATION WS 220 | WS 589 |
|---|---|---|
| Center Wing | 0.06 | - |
| Center Wing + Outer Wing (No outb'd or inb'd nacelles) | 0.40 ± 0.10 | 4.0 ± 0.20 |
| Center Wing + Outer Wing + Inb'd and Outb'd nacelles | 0.80 ± 0.10 | 8.0 ± 0.20 |
| Center Wing + Outer Wing + Inb'd Nacelle Only | 0.50 ± 0.10 | 5.0 ± 0.20 |
| Center Wing + Outer Wing + Outb'd Nacelle Only | 0.65 ± 0.10 | 6.70 ± 0.20 |

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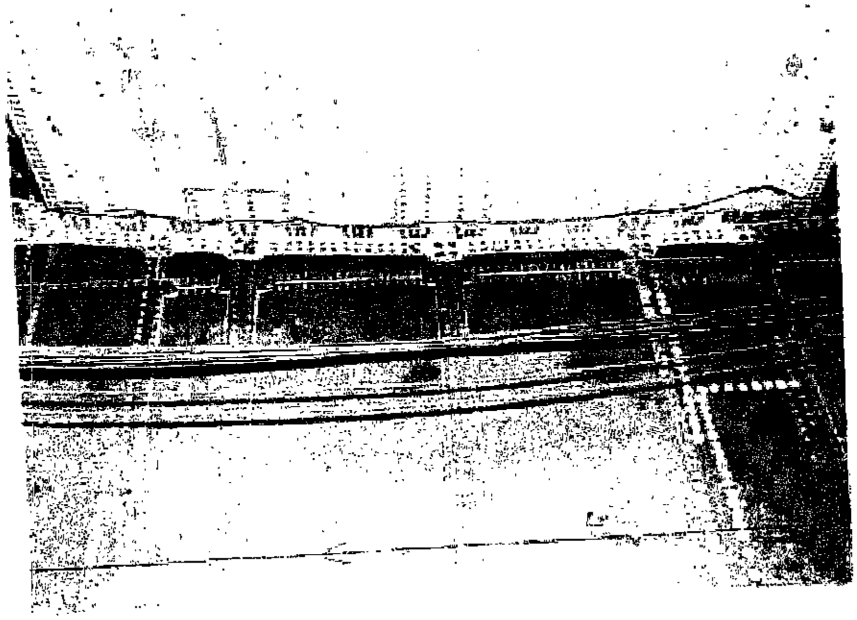
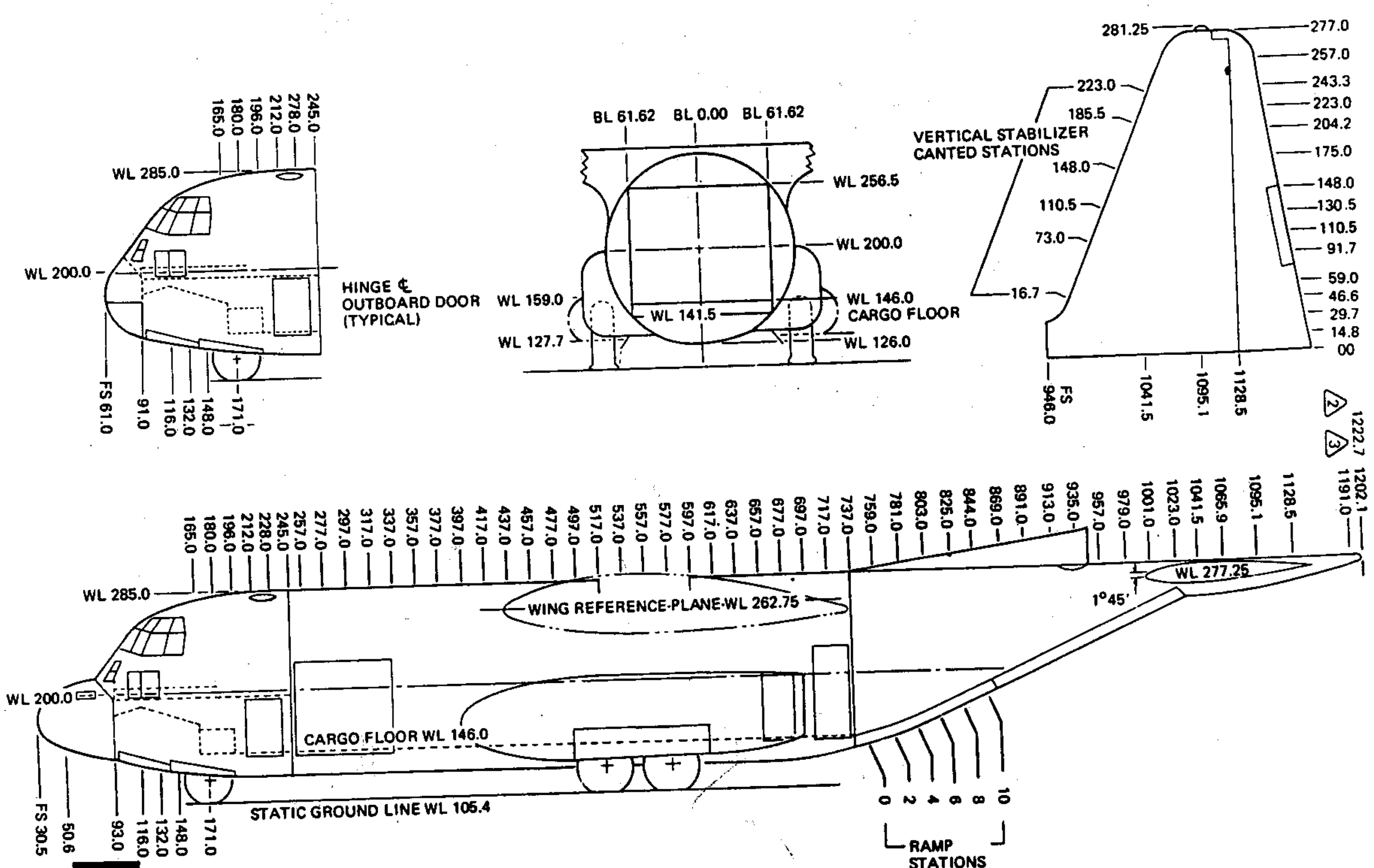


[illegible]

Figure [illegible] - View looking [illegible] wing section, [illegible] - [illegible], [illegible] Broken skin [illegible] stringers

[illegible]

Figure [illegible] - View looking aft [illegible] Center wing section
Failure [illegible] cycles




**NOTE**

1. FUSELAGE STATION NUMBERS ARE GIVEN ON THE FUSELAGE RINGS AND INSULATION AT TWENTY-INCH INTERVALS FROM FUSELAGE STATION 93 TO 1041.5.

(2) ALL AIRPLANES NOT MODIFIED BY T O 1C-130-728.

(3) ALL AIRPLANES MODIFIED BY T O 1C-130-728.

*Figure 1-1. Airplane Station Diagram (Airplanes AF53-3129 through 55-020, 55-022 through 57-483, and 57-496 and Up) (Sheet 2 of 5)*

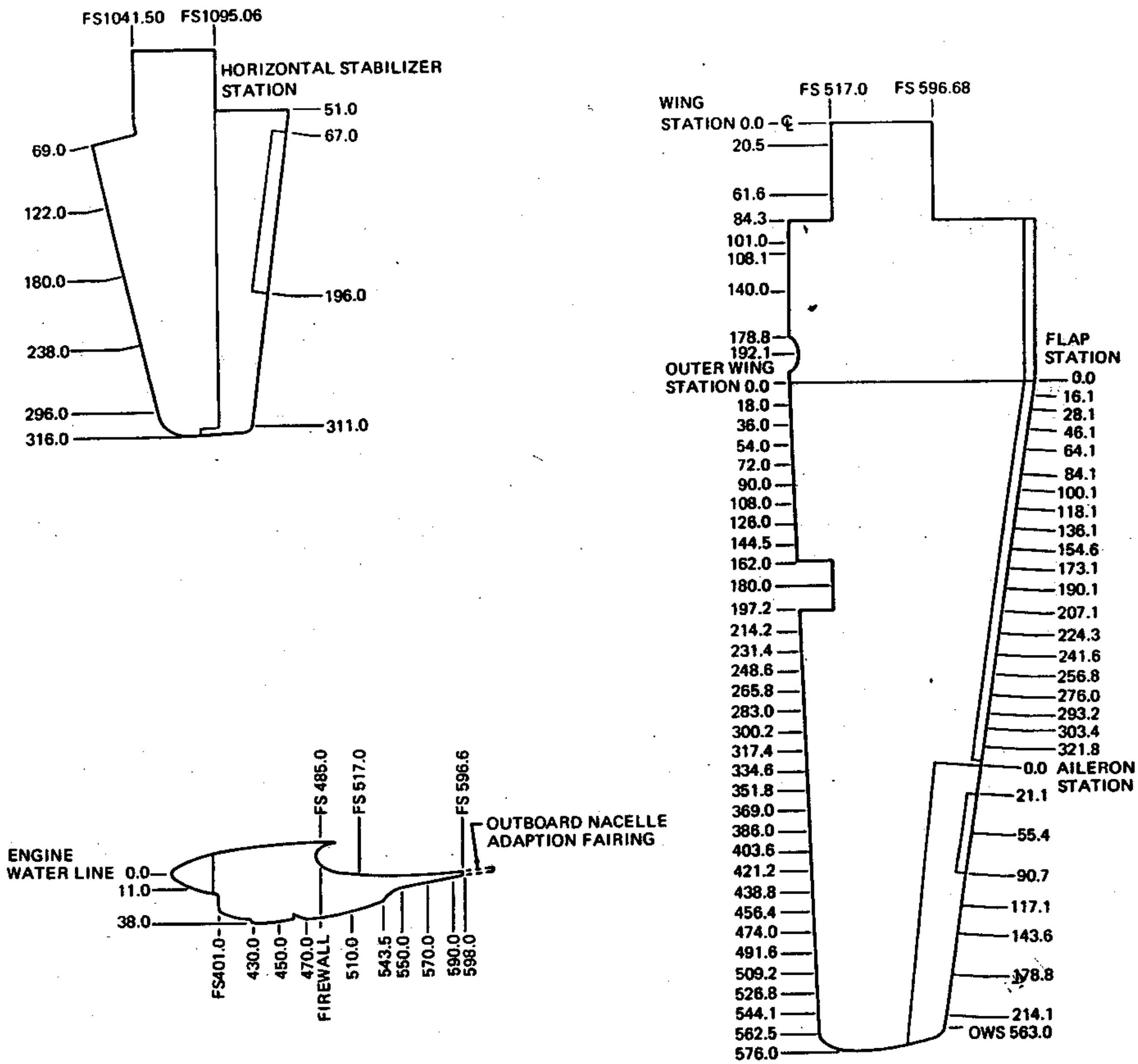



*Figure 1-1. Airplane Station Diagram (Airplanes AF53-3129 through 55-020, 55-022 through 57-483, and 57-496 and Up) (Sheet 1 of 5)*

GP

### *C-130A Fatigue Test*

The C-130A hydro-fatigue test was conducted during the period from September 1956 through December 1958. The test article experienced a total of 459 failures, three of which were not fail safe, and had they occurred on an aircraft in flight, it would have been catastrophic. The remaining failures varied in severity but all were considered fail safe in that loss of the aircraft would have been extremely unlikely even though fuselage pressurization was lost on some.

The C-130A hydro-fatigue test was conducted early in the development of the aircraft and the results of this test led to an extensive production redesign of the fuselage. Skin gages were increased appreciably. The skin material was changed from 7075-T6 to a more damage tolerant, corrosion resistant 2024-T3 aluminum. Fail safe structure was incorporated to preclude catastrophic failures. Extensive detail design changes were made to reduce stress concentration in local areas. The shell stress due to normal operating pressurization of 7.5 psi was reduced from a maximum of 19,000 psi to 13,000 psi to im rove the fatigue properties of the structure and to reduce the rate of fatigue crack gr

C130 SERVICE LIFE ANALYSIS ATTACHMENTS

Full scale fatigue ... s conducted from 1960 to 1964. Structural components invest ... , main landing gear, nose landing gear, and the empennage. Th ... load regimes which typified USAF usage at the time. This was ... missions:

1. Short Range ...
2. Short Range Logistics,
3. Long Range Logistics, and
4. Training.

The wing test article consisted of left and right outer wings, and the center wing mounted on a center fuselage (the center fuselage was considered to be part of the test fixture used to balance loads). The empennage test article was composed of a structurally complete horizontal stabilizer, vertical stabilizer, and aft fuselage cantilevered off a steel bulkhead. The MLG specimen was two MLG struts with dummy wheels, the torque link, and the wheel well panel mounted in a test frame. The NLG specimen had only a strut assembly with dummy wheels mounted in a test frame.

The scheduled inspection frequencies for the test articles were:

| | |
|---|---|
| Wing | 3000 simulated flight hours |
| Main Landing Gear | 3000 simulated landings |
| Nose Landing Gear | 4000 simulated flights |
| Empennage | 3000 simulated flight hours |

The C-130B wing fatigue test was characterized by severe downbending. A conservative evaluation of ground conditions and operations resulted in test loads spectra that imposed considerable fatigue damage on the upper surface. The following structural modifications were instituted as a result of this test program:

- Incorporation of steel straps on the forward-upper center wing beam cap.
- Integral doublers around access doors and fuel filler cap.
- Tapered bushings and protruding head fasteners at fuel bag access door.

## *C-130E Wing Fatigue Tests*

A second full scale wing fatigue test was conducted on a C-130E wing from February 1966 through March 1970. The loads spectra for this test simulated a large percentage of high-speed, low-altitude flight and a large percentage of rough runway operations. The sequence of fatigue susceptibility demonstrated by this test was:

1. Center wing lower surface
2. Center wing upper surface
3. Outer wing lower surface
4. Outer wing upper surface

After 23,000 simulated flight hours the center wing had been repaired to the extent that it was no longer representative of an airworthy wing. The test loads were adjusted to reduce the center wing loading and the test continued until 30,000 simulated flight hours had been imposed on the outer wing.

Major structural modifications resulting from this test and associated component tests were:

1. Major redesign of the center wing, including
   - Forward and aft fastener holes in the pattern around the fuel filler cap were eliminated.
   - Clamp in WS 0.0 access door.
   - Reinforcing beams at WS 58 and WS 181 lower surface were tapered more and interference fasteners were installed at the ends of the beams.
   - Reduction in maximum design ultimate stress from 58,000 psi to 46,800 psi.
   - Material change to 7075-T7351.
2. ECP 954 - A collection of fatigue preventive modifications for the existing outer wing structure.

## *C-130B/E In-Service Wing Fatigue Damage*

Sample inspections of the USAF C-130 airplanes in mid-1967 provided visual evidence, in the form of fatigue cracks in the center wing, that some aircraft were accumulating a significant amount of fatigue damage at an accelerated rate. These inspection reports confirmed the need for an immediate inspection of the C-130 airplanes to verify the existence of a C-130 center wing fatigue problem.

The problem had been created by the evolution of the C-130A model airplane to the C-130B and E models which provided an increase in range, payload and fuel capacity to meet new operational requirements. To provide increased fuel capacity, fuel cells were added to the center wing cavity necessitating fuel filler neck cutouts at upper Wing Station 120.5 on the left and right sides, a dry bay access door at Center Wing Station 1.5, and fuel cell access doors at Center Wing Station 120.5 on the lower left and right sides of the center wing. Internal doublers and "I" beams were installed to restore the load carrying capability of the areas where holes were cut in the upper and lower panels. These changes resulted in areas of high stress concentration which led to cracking in the cutout areas and in the associated backup structure. WR-ALC briefed AFLC on the fatigue problem and recommended a course of action on 1 September 1967. AFLC promptly directed the following actions:

- Publish Inspection Technical Order 1C-130-798, Inspection of C-130 Center Wings for Cracks .
- Dispatch contract field teams / depot teams to all C-130 bases to inspect aircraft at bases.
- Inspect all aircraft being processed through depot maintenance facilities.
- All inspections to be observed and results reported to WR-ALC by a qualified engineer to ensure quality inspection.
- Full participation by industry, ASD, AFLC, and using commands to study the problem and recommend corrective measures.

A task group, consisting of a C-130 control center and five working panels, was established at WR-ALC on 1 September 1967. The control center and the five working panels were chaired by WR-ALC with membership from industry, AFLC, ASD, Division Advisory Group for ASD, MAC, TAC, and PACAF. This task group was assigned the task to study the cause and extent of the problem, seek various solutions to the problem, and in conclusion, recommend optimum solutions that would consider the immediate impact, as well as a long range impact, for effective fleet management.

The results of the output from the task group implemented several integrated programs:

- C-130 Southeast Asia (SEA) Environmental Loads and Recording Program: Investigation proved that significant portions of existing environmental and dynamic response data was insufficient and outdated.
- C-130 Fatigue Life Monitoring Program: The structural state of each aircraft was modified for more effective planning in utilization, modifications, and inspections.
- C-130B/E Center Wing Modification Program: Lockheed submitted LCP 750 for WR-ALC evaluation in February 1968. This proposal proved to be a logical solution to the C-130 center wing structural problem because the proposed installation of an improved redesigned center wing box beam would provide a 10,000 hour life extension for the C-130B/E force.
- C-130B/E Wing Fatigue Test Program: Lockheed submitted ECP 790 in February 1968 for WR-ALC evaluation. The objective of this program was to support the center wing modification program. This was accomplished by component testing (Phase I) and a full scale fatigue test of the wing (Phase II) to four lifetimes (40,000 test hours).
- C-130 Landing Gear Modification Program: Lockheed submitted ECP 783 to WR-ALC for evaluation. This was a modification to the main landing gear and backup structure to alter the influence of gear loads on the wing in order to extend the service life of the new center wing.

WR-ALC recommended to HQ AFLC on 28 March 1968, based on the results of this task group, that the following actions be taken to ensure the capability to adequately resupply the C-130 to forward areas where runways are rough and difficult to maintain:

- Procure the landing gear modification, contingent on test results.

- Procure the new, redesigned center wing box beam.
- Procure the fatigue test program for the new center wing.
- Procure ECP kits 912, 939, and 941, as necessary, to protect the C-130 force, pending installation of the new center wing.
- Continue the C-130 SEA Environmental Loads and Recorder Program and the C-130 Fatigue Life Monitoring Program.

HQ AFLC approved the above recommendations without change and directed that WR-ALC brief HQ USAF. HQ USAF was briefed by WR-ALC on 2 April 1968 who approved the above recommendations.

The Center Wing Modification Program (T.C.T.O. 1C-130-819) was completed on 460 USAF C-130B and E model airplanes between 1968-1972. This same new center wing design was incorporated into the baseline configuration beginning with the FY '68 procurement.

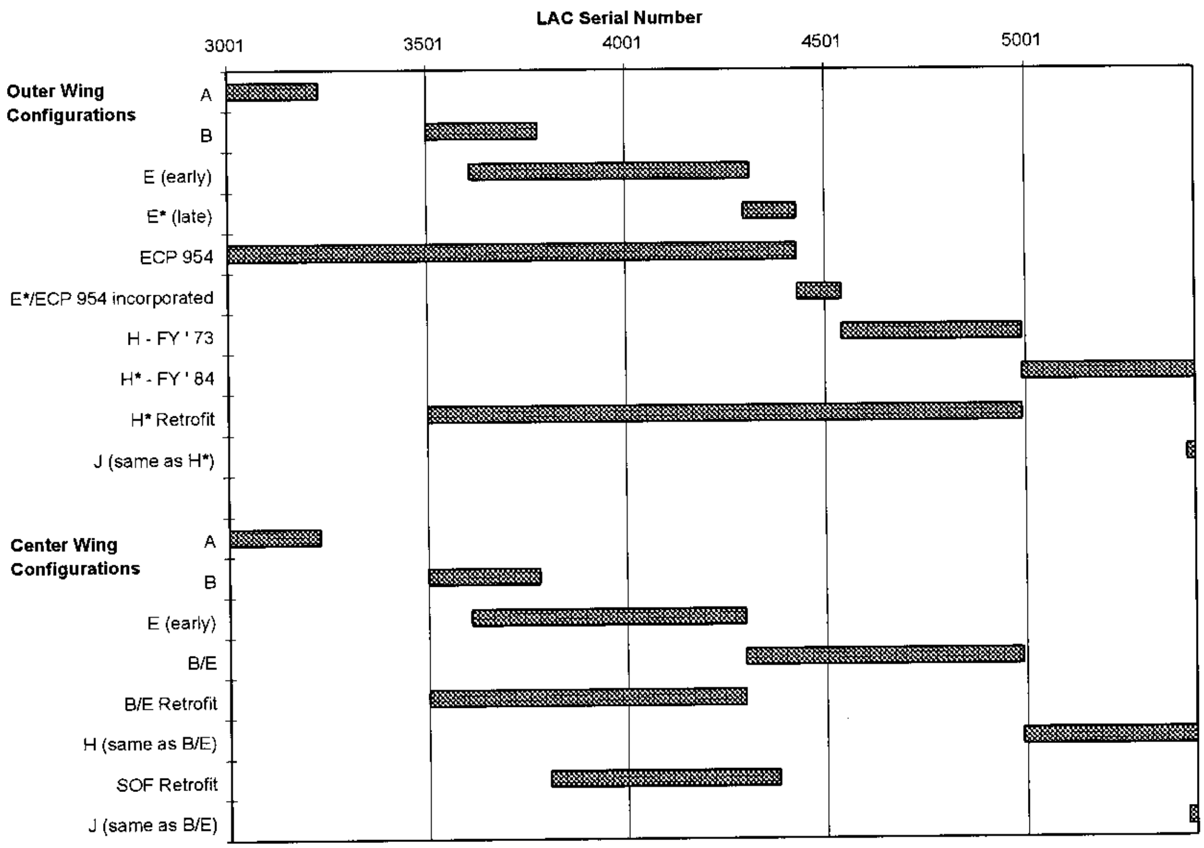
### *C-130B/E Wing Fatigue Test*

A third full scale wing fatigue test, entitled the C-130B/E wing test, was conducted during 1970-1973 to determine the fatigue life of the new, redesigned C-130B/E center wing and to obtain some measurement of the effectiveness of the ECP 954 outer wing fatigue preventative modification (T.C.T.O. 1C-130-857). The loads spectrum for this test was characterized by severe wing upbending, resulting from a large percentage of assault cruise missions, and mild downbending, resulting from a predominance of first class paved runways. The test article was subjected to cyclic loadings representing a period of four life times (43,000 test hours).

Performance of the new center wing exceeded expectations of both WR-ALC and Lockheed engineering. Discounting the insignificant nuisance type damages (popped fasteners, fairing cracks), the center section box beam sustained nearly 15,000 simulated flying hours of testing without experiencing a single fatigue crack. After 15,000 hours test time, some fatigue damage was found but none was catastrophic nor of major proportions. All were easily repaired and no modifications were recommended for service aircraft.

The C-130A model airplanes were not included in the outer wing replacement program because the C-130H outer wing does not mate to the C-130A model center wing. A rehab program was conducted, however, that rehabilitated the C-130A model center and outer wings during depot maintenance, as needed.

The following figure is a time-line portrayal of the major design improvements that have occurred on the C-130 wing components.




*C-130 Wing Design Improvements*

| Model | Tested to | Remarks |
|---|---|---|
| C-130A | 89% ultimate Flight Loads | Upper surface failed at OWS 21. Reinforcements added to fleet. No retest. |
| C-130B | 93% ultimate Flight Loads | Upper surface failed at OWS 54. Reinforcements added to fleet. No retest. |
| C-130E | 110% ultimate Flight Load | Upper surface of center wing failed at WS 128. Test acceptable. |

**Wing Static Tests**