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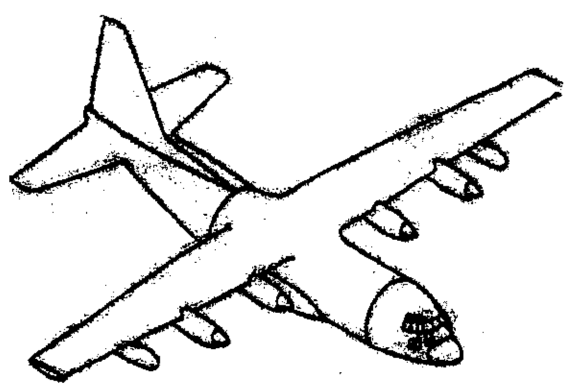
F09603-78-G-0745

C-130 A
Durability and Damage Tolerance Assessmen
(DADTA) :
Crack Growth Analysis



PREPARED FOR

UNITED STATES AIR FORCE
WARNER ROBINS AIR LOGISTICS CENTER
ROBINS AFB, GEORGIA

Lockheed-Georgia Company
A Division of Lockheed Corporation
Marietta, Georgia 30063

ABSTRACT

This report presents the results of crack growth analyses performed on the C-130A primary airframe structure, using baseline representative average operational loads spectra, during the C-130 Durability And Damage Tolerance Assessment (DADTA) Program. The major portion of this report is dedicated to the presentation of the results of crack growth analysis of individual critical areas of the C-130A structural airframe. The results of these crack growth analyses are then used to make recommendations for the safe operation of the C-130A force. The resultant recommendations are combined into an options matrix which can be used to formulate a Force Structural Maintenance Plan, as reported in Lockheed-Georgia Report, LG81ER0152.

FOREWORD

The crack growth analyses, presented in this report, were performed during the Durability And Damage Tolerance Assessment (DADTA) of the C-130 airframe. All the analyses, contained in this report, were conducted by Lockheed-Georgia Company, under contract to Warner Robins, Contract No. F09603-78-G-0745, Order No. 0014. The Warner Robins Project Engineer is Mr. James A. Wagner.

Other reports related to the C-130 DADTA program are as follows:

LG78ER0258: C-130 DADTA Planning and Scheduling Report
LG78ER0270: C-130 DADTA Test Plan
LG80ER0030: C-130A/B/E/H DADTA Interim Report
LG81ER0146: C-130 DADTA Test Program
LG81ER0147: C-130 DADTA General Methodology
LG81ER0149: C-130B DADTA Crack Growth Analysis
LG81ER0150: C-130E/E* DADTA Crack Growth Analysis
LG81ER0151: C-130H DADTA Crack Growth Analysis
LG81ER0152: C-130A/B/E/E*/H DADTA Summary Report

Appreciation, for their contributions to this report, is extended to:

R. J. Birdseye	W. C. Gray	C. S. Sarphie
D. T. Colston	M. R. Kelley	C. D. Ware
K. C. Cornelius	R. A. Malecki	G. C. Watson
T. W. Deiters	M. R. Orlandella	D. B. Willey
L. C. Eanes	J. S. Phillips	B. K. Young
M. T. Edwards	R. D. Rice	W. F. Young

GLOSSARY

a	Crack Length
a_c	Critical Crack Length
AFTO	Air Force Technical Order
ASIP	Aircraft Structural Integrity Program
b	Material Thickness
β	Geometric Correction Factor
$\beta(a)$	Geometric Correction Factor Referenced to the Crack Length Scale a
β_T	Total Correction Factor
C	Forman Equation Material Constant
CW	Center Wing
da/dN	Rate of Crack Growth, Inches/Cycle
da/dP	Rate of Crack Growth, Inches/Pass
D	Hole Diameter, Inches
DADTA	Durability And Damage Tolerance Assessment
DART	Damage Analysis in Rapid Time
Δ	Delta, Incremental
f	Stress
$f\ (\Delta K)$	Function of K
f_{ty}	Yield Stress
F	Fuselage
HRS	Hours
HT	Horizontal Tail
IN	Inches

GLOSSARY (Continued)

IAT	Individual Aircraft Tracking
Kip	One Thousand Pounds
KSI	Kips Per Square Inch
K	Stress Intensity Factor, KSI IN
K_c	Critical Stress Intensity Factor, Plane Stress or Mixed Mode, KSI $\sqrt{IN}$
K_T	Uncracked Stress Concentration Factor
K_{Ic}	Critical Stress Intensity Factor, Plane Strain, KSI $\sqrt{IN}$
ΔK	Stress Intensity Factor Range Parameter, KSI $\sqrt{IN}$
L	Total Crack Length
M_X	Bending Moment About X Axis, Inch-Pounds
M_Y	Bending Moment About Y Axis, Inch-Pounds
M_Z	Bending Moment About Z Axis, Inch-Pounds
$\bar{M}_X$	Mean Bending Moment About X Axis
$\bar{M}_Y$	Mean Bending Moment About Y Axis
MDS	Model/Design/Series
No.	Number
n_{cg}	Acceleration, g's, at Center of Gravity
n_g	Acceleration, g's, At Main Gear
n_X	Acceleration, g's, X Direction
n_Y	Acceleration, g's, Y Direction
n_Z	Acceleration, g's, Z Direction
$\bar{n}_Z$	Mean Acceleration, g's, Z Direction
n	Forman Equation Material Constant

GLOSSARY (Continued)

N/P or NAC/PYL	Nacelle/Pylon
NASTRAN	NASA Structural Analyses Program
OW	Outer Wing
OWE	Operating Weight Empty
OWS	Outer Wing Station
P	Pressure Load
P_X	Load in X Direction, Pounds
P_Y	Load in Y Direction, Pounds
P_Z	Load in Z Direction, Pounds
PSD	Power Spectral Density
r	Hole Radius
R	Range Ratio
REP	Representative
R/R	Runway Roughness
ρ	Ratio of Local Average Stress to Remote Stress
σ	Stress
$\bar{S}$	Mean Stress
S/L	Stress-To-Load Ratio
$_c$	Instability Stress
TAG	Taxi-Air-Ground (Flight Test Program)
T.O.	Take Off
τ	Shear Stress
UTIL	Utilization
VERT	Vertical

GLOSSARY (Continued)

VGH	Velocity, Acceleration, Altitude
VT	Vertical Tail
W	Wing
WS or W.S.	Wing Station
β_1	Constant
β_2	Secant Finite Width (Reference 29)
β_3	General Tabular
β_4	Kobayashi's Backface (Reference 29)
β_5	Isida's Eccentric Crack (Reference 29)
β_6	Bowie Factor (Reference 29)
β_7	Filled/Loaded Hole (LOHL) (See Section 8.3.2)
β_8	Poe's Stiffened Sheet Analysis (Reference 28)
β_9	Eccentric Crack From Hole (Isida) (See Section 8.3.2)
β_{10}	Hole Edge Correction, Ligament Failed (QSLOT) (See Section 8.3.2)
β_{11}	C-141 Center Wing Lower Panel 11
β_{12}	C-141 Access Hole in Wing Surface
β_{13}	Adjacent Hole
β_{14}	Overlap Plate Joint
β_{15}	C-141 Lower Rear Spar Cap at BL 59
β_{16}	C-141 Rear Spar Cap at IWBRS 86
β_{17}	CWSS-Center Wing Spanwise Splice
β_{18}	WS61U-Upper Rear Beam Cap-Aft Horizontal Cap Flange at WS 61.125
β_{19}	WS61L-Lower Rear Beam Cap-Aft Edge of Skin Panel at WS 59.99

GLOSSARY (Continued)

β_{20}	WS79-Lower Rear Beam Cap-Cap Crack at WS 79.63
β_{21}	LSSS-Lower Surface Spanwise Splice-WS 185
β_{22}	WS220L-Lower Surface Wing Splice-Panel Crack at WS 212.69
β_{23}	OWS6-Lower Surface Wing Splice-Panel 2 Crack at WS 223.5
β_{24}	OWS6-Lower Surface Wing Splice-Panel 3 Crack at WS 223.5
β_{25}	OWS6-Lower Surface Wing Splice-Rainbow Fitting Crack at WS 223.5
β_{26}	OWS35-Lower Surface Weephole at WS 255
β_{27}	OWS35-Lower Surface King Pin Fitting Attachment at WS 255
β_{28}	OWS108-Lower Rear Beam Cap at WS 326.6
β_{29}	OWS162-Lower Front Beam Cap at WS 372.87
β_{30}	OWS162-Lower Front Beam Cap at WS 380.79
β_{31}	OW162-Lower Surface Panel 1 Along Drag Angle at WS 382.23
β_{32}	OWS287-Lower Surface Panel 4 Runout at WS 507
β_{33}	OWSS-Outer Wing Spanwise Splice-Outer Tab Cracking
β_{34}	OWSS-Outer Wing Spanwise Splice-Inner Tab Cracking
β_{35}	GENSPLC-General Splice-Fuselage Circumferential Splice or Wing Chordwise Splice

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Figure 4.1: Center Wing Lower Surface, Summary of Critical Areas

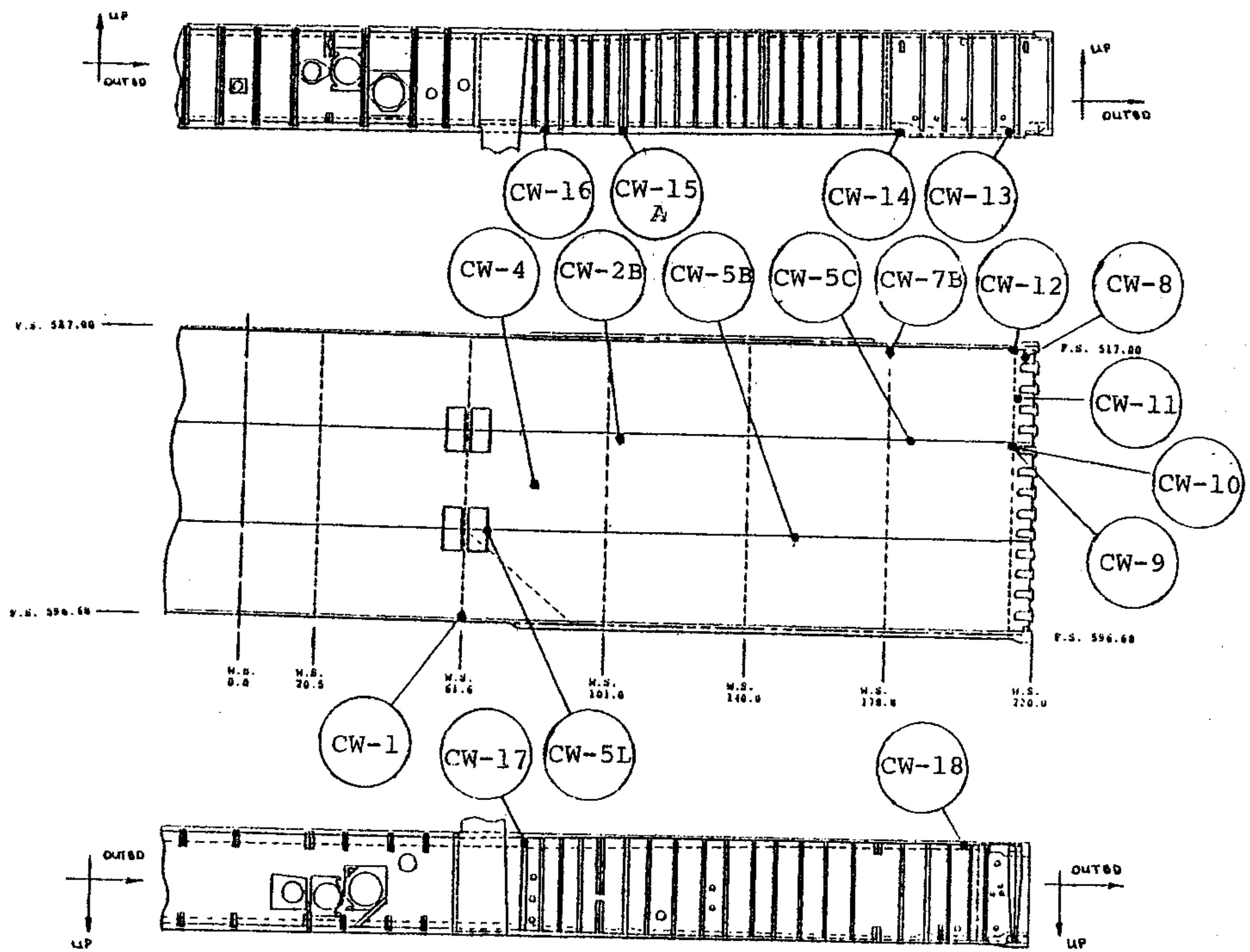

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FIGURE 8.5.1 : ANALYSIS POINT: CW-5C

CENTER WING LOWER SURFACE GENERAL SPANWISE SPLICE AT W.S. 185.5

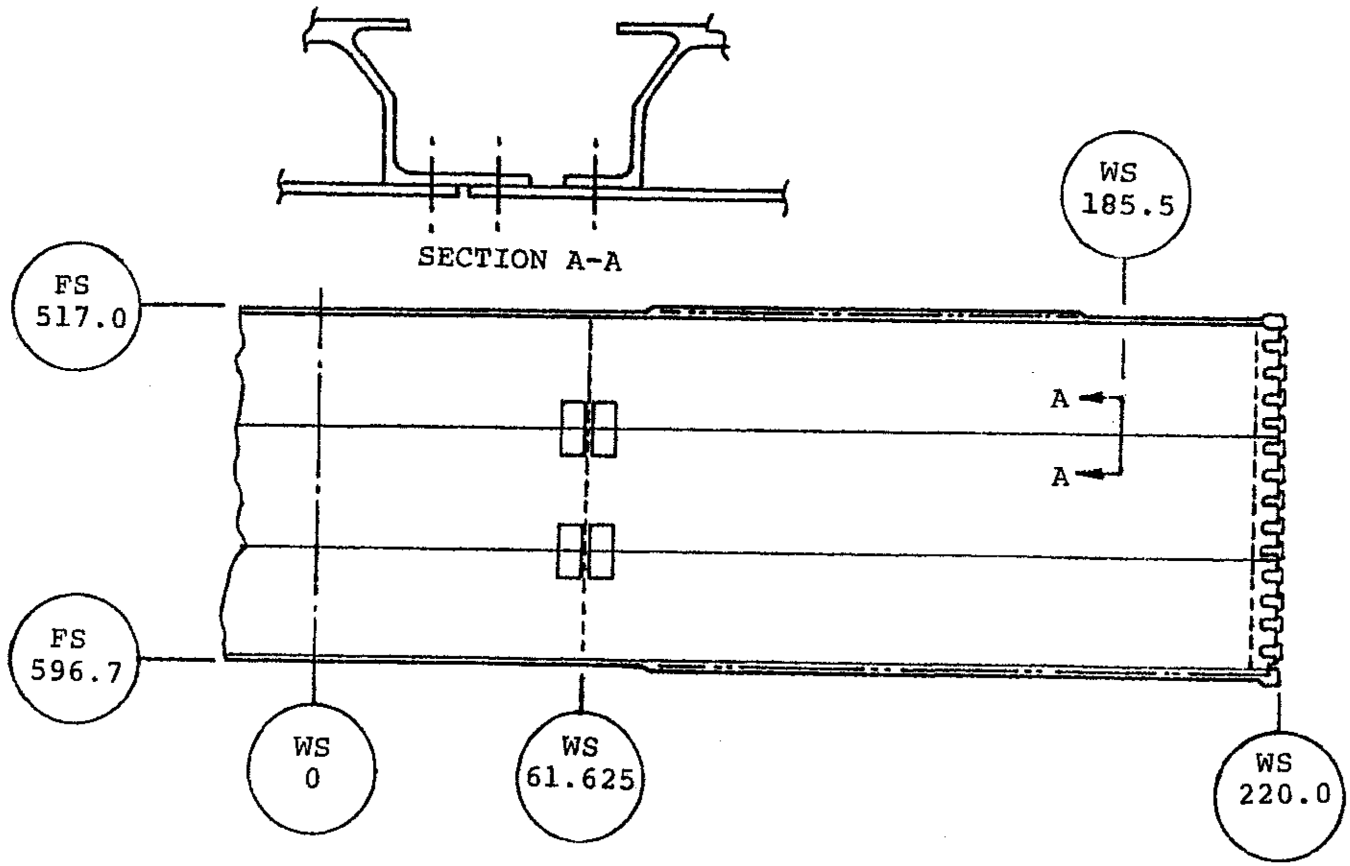

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Figure 2.1: Operational Limits: Center Wing Lower Surface

ANALYSIS POINT	DESCRIPTION	CRITICAL ELEMENT	CRITICAL CRACK LENGTH, a_{CRIT} AT DESIGN LIMIT STRESS		SAFETY LIMIT	UNMOD. STRUCTURE LIMIT
			a_{CRIT} INS.	D.L.S. K.S.I.	FLT. HRS.	FLT. HRS.
CW-1	Panel No. 3 at Rear Beam, WS 61.6	Panel	1.90	33.33	8,283	11,485
CW-2B	Panel No. 2 Drain Holes, WS 109.5	Panel	4.00	36.23	19,509	32,965
CW-4	Panel No. 2 Fairing Attach Holes, WS 80.0	Panel	5.48	36.25	13,575	20,691
CW-5B	Panel 2/3 General Spanwise Splice, WS 151.0	Panel	1.49	36.49	5,539	11,542
CW-5C	Panel 1/2 General Spanwise Splice, WS 185.5	Panel	1.72	35.67	5,370	12,564
CW-5L	Panel 2/3 Splice at Doubler Instl., WS 68.5	Panel	1.60	39.26	5,332	9,429
CW-7B	Panel No. 1 at Engine Drag Fitting, WS 178.0	Panel	2.68	30.57	3,749	7,173
CW-8	Panel No. 1 at Corner Fitting, WS 214.0	Panel	2.04	31.34	9,076	14,290
CW-9	Panel No. 2 at Rainbow Fitting, WS 214.0	Panel	3.42	31.74	3,128	4,822
CW-10	Splice Angle at Rainbow Fitting, WS 214.0	Splice Angle	1.37	31.74	46,463	74,344
CW-11	Rainbow Fitting, WS 214.0	Fitting	0.82	31.74	51,643	76,268
CW-12	Forward Corner Fitting, WS 214.0	Fitting	1.48	31.34	22,190	38,857

FIGURE 8.5.4 ANALYSIS POINT CW-5C; BETA FORMULAS

CENTER WING LOWER SURFACE GENERAL
SPANWISE SPLICE AT WS 185.5

PHASE	FORMULA
I	$\beta_{TOTAL} = .712\ \beta_7\ (a')\ \beta_4\ (a/b)$
II	$\beta_{TOTAL} = \beta_7\ (a)$
III	$\beta_{TOTAL} = \frac{.712}{1.12}\ \beta_{10}\ (a')\ \beta_{17}\ (a')\ \beta_4\ (a/b)$
IV	$\beta_{TOTAL} = \frac{1}{1.12}\ \beta_{13}\ (a)\ \beta_{17}\ (a)$

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FIGURE 8.5.5 ANALYSIS POINT: CW-5C; OPERATIONAL LIMITS

CENTER WING LOWER SURFACE GENERAL SPANWISE SPLICE AT W.S. 185.5

PHASE	SAFETY LIMIT		DURABILITY LIMIT	
	CRACK LENGTH (IN)	FLIGHT HOURS	CRACK LENGTH (IN)	FLIGHT HOURS
I	.050-.089	1470	.010-.089	8477
II	.089-.315	2085	.089-.315	2085
	Δa = .0011		Δa = 0.0	
III	.5111-.594	978	.510-.594	1165
IV	.594-1.715	837	.594-1.715	837
	$\sum$ = 5,370		$\sum$ = 12,564	

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FIGURE 8.5.2 ANALYSIS POINT: CW-5C; BASIC DATA

CENTER WING LOWER SURFACE GENERAL SPANWISE SPLICE AT W.S. 185.5

EFFECTIVE STRESS LOAD RATIO (AXIAL STRESS/UNIT M_X)	.001839
BEARING/BY-PASS RATIO	.650
ASSUMED INITIAL FLAW SIZE, a_i	.050 IN.
NUMBER OF CYCLES PER PASS	229,460
MAXIMUM SPECTRUM TENSION STRESS	25.084 KSI
ONCE PER 10,000 HOUR TENSION STRESS	
DESIGN LIMIT GROSS TENSION STRESS	35.671 KSI
CRITICAL CRACK LENGTH, a_{CRIT}, AT DESIGN LIMIT STRESS	1.715 IN.

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FIGURE 8.5.3 ANALYSIS POINT: CW-5C; CRACK GROWTH SEQUENCE

CENTER WING LOWER SURFACE GENERAL SPANWISE SPLICE, WS 185.5

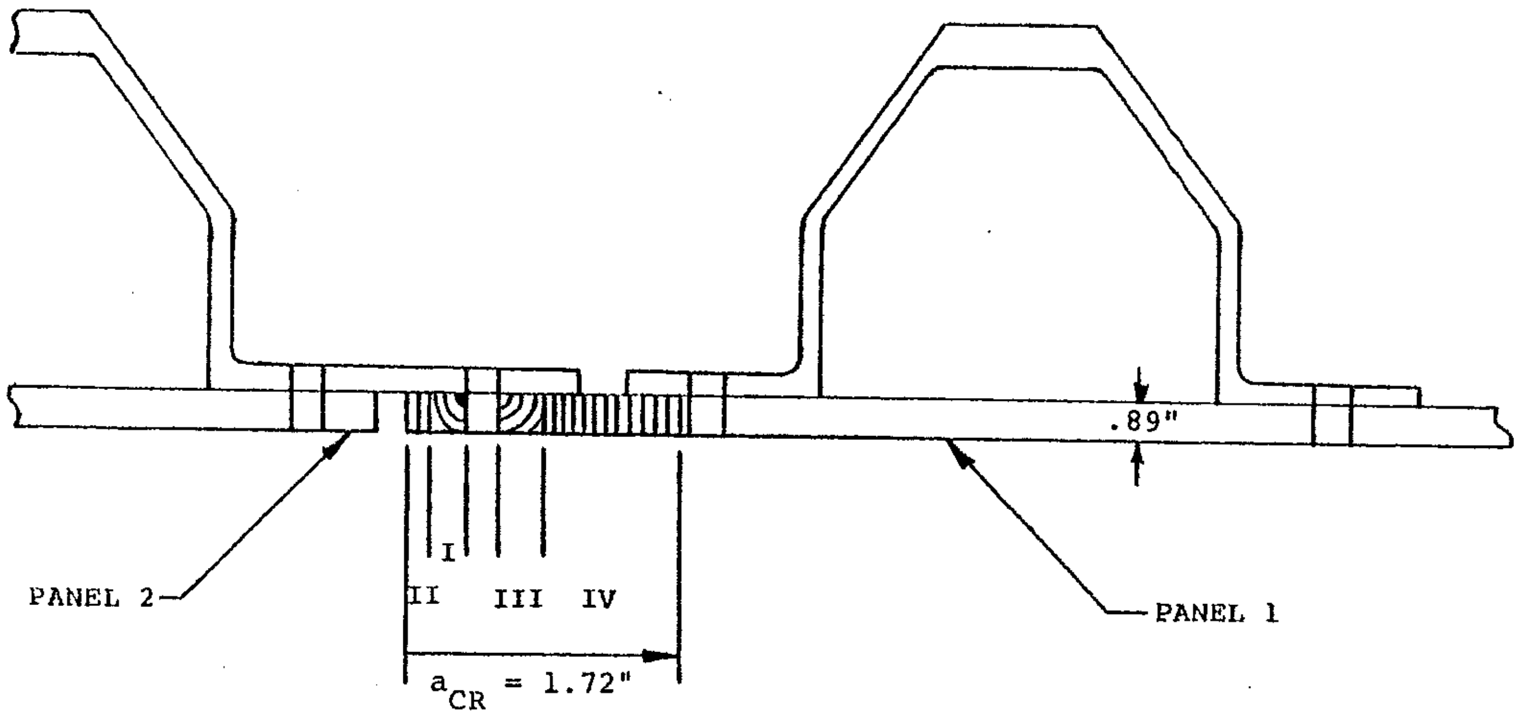

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FIGURE 8.5.6 ANALYSIS POINT CW-5C; CRACK GROWTH CURVE

CENTER WING LOWER SURFACE SPANWISE SPLICE
AT WS 185.5