This file contains Appendcies F-J of
Aircraft Aged-Related Degradation Study on Single- and Three-Phase Circuit Breakers,
DOT/FAA/AR-01/118

APPENDIX F—PROCESS 1 RESULTS AND FAILURE ANALYSIS REPORTS

Block Number (#)	Manufacturer		Visual (See Inventory Sheet) & X-Ray Photo # (1)		(2)	Open Breakers only: Close & X-Ray Photo # (3) (4)		(5)	150% or 200% Overload Cal. (6)				(10)	(11)	400%, 500% or 600% Overload Cal. (12)				(16)	Comments Provided below	X-Ray Button View
Sample Number	Part Designator	Date Code	Sample#-Wide View	Sample#-Narrow View	Breaker Open/ Closed	Sample#-Wide View	Sample#-Narrow View	L.V.C.R. Avg (mV)	LVCR Max (mV)	Temp. Rise (°C)	Overload %	P/F ? (7)	Close Breaker	L.V.C.R. Avg (mV)	LVCR Max (mV)	Temp. Rise (°C)	Overload %	P/F ? (13)	L.V.C.R. Avg (mV)	(1,2, etc)	Sample#-Button
AD001	A - 3	0974A	WX1P1	NX1P1	Closed			17.1	253	4	200	Pass	X	55.04	105	1	500	Pass	25.56	4	
AD002	A - 3	0974A	WX1P1	NX1P1	Closed			14.56	258	5	200	Pass	X	35.68	71	1	500	Pass	45.71	4	
AE007	A - 5	1091A	WX1P1	NX1P1	Open	WX1P4	NX1P4	8.14												2	
AE008	A - 5	0792A	WX1P1	NX1P1	Closed			7.92	234	4	200	Pass	X	11.50	32	3	500	Pass	8.04	4	
AH012	A - 10	0974A	WX1P1	NX1P1	Closed			2.27	244	6	200	Pass	X	3.25	126	4	500	Pass	5.75	4	
BA020	L - .5	7207	WX1P1	NX1P1	Closed			489.35	430	2	200	Pass	X	488.20			N/A			3	
BA021	L - .5	8203	WX1P1	NX1P1	Closed			449.18	396	3	200	Pass	X	450.70			N/A			3	
BD027	A - 3	0374A	WX1P1	NX1P1	Open	WX1P4	NX1P4	16.39												2	
BD028	A - 3	0874A	WX1P1	NX1P1	Closed			17.44	333	8	200	Pass	X	88.08	88	2	500	Pass	232.58	4	
BD029	A - 3	0374A	WX1P1	NX1P1	Closed			15.74	328	5	200	Pass	X	58.62	201	3	500	Pass	21.25	4	
BE039	A - 5	0674A	WX1P1	NX1P1	Open	WX1P4	NX1P4	7.84												2	
BE040	A - 5	0674A	WX1P1	NX1P1	Closed			7.94	198	6	200	Pass	X	48.89	125	3	500	Pass	25.54	4	
BH045	A - 10	0674A	WX1P1	NX1P1	Open	WX1P4	NX1P4	2.24	345	6	200	Pass	X	10.76	94	4	500	Pass	5.23	4	
BH046	A - 10	0674A	WX1P1	NX1P1	Closed			2.45												2	
BH047	A - 10	0674A	WX1P1	NX1P1	Closed			2.32	220	5	200	Pass	X	2.00	62	5	500	Pass	5.00	4	
CD066	A - 3	0874A	WX1P1	NX1P1	Open	WX1P4	NX1P4	17.18												2	
CD067	B - 3	0489A	WX1P1	NX1P1	Closed			16.05	295	4	200	Pass	X	59.41	75	3	500	Pass	16.19	4	
CD068	B - 3	0887A	WX1P1	NX1P1	Closed			16.4	266	6	200	Pass	X	28.79	158	3	500	Pass	35.80	4	
CE079	A - 5	0289A	WX1P1	NX1P1	Closed			7.47	254	7	200	Pass	X	12.34	13	4	500	Pass	10.57	4	
CH084	H - 10	7807	WX1P1	NX1P1	Closed			2.52	219	0	200	Pass	X	3.17			N/A			3	
DA091	L - .5	9346	WX1P1	NX1P1	Closed			454.13	441	0	200	Pass	X	455.10			N/A			3	
DA092	L - .5	7417	WX1P1	NX1P1	Closed			458.77	424	0	200	Pass	X	459.50			N/A			3	
DA093	L - .5	7425	WX1P1	NX1P1	Closed			465.55	339	4	200	Pass	X	453.70			N/A			3	
DA094	L - .5	7408	WX1P1	NX1P1	Closed			455.27	391	4	200	Pass	X	455.80			N/A			3	
DA095	L - .5	7439	WX1P1	NX1P1	Closed			474.6	496	4	200	Pass	X	474.30			N/A			3	
DE116	A - 5	0874A	WX1P1	NX1P1	Open	WX1P4	NX1P4	7.88												2	
DE117	A - 5	0874A	WX1P1	NX1P1	Open	WX1P4	NX1P4	8.18	234	7	200	Pass	X	61.95	104	2	500	Pass	10.40	4	
DE118	A - 5	0996	WX1P1	NX1P1	Closed			8.18	233	8	200	Pass	X	25.72	4	4	500	Pass	20.96	4	
DH137	A - 10	1274A	WX1P1	NX1P1	Closed			2.16	245	3	200	Pass	X	2.72	157	2	500	Pass	2.97	4	
DH138	A - 10	0974A	WX1P1	NX1P1	Closed			2.61												2	
BD303	A - 3	0374A	WX1P1	NX1P1	Closed			118.7	286	7	200	Pass	X	67.63	57	1	500	Pass	56.30	4	
CD304	B - 3	9138	WX1P1	NX1P1	Closed			17.85	276	7	200	Pass	X	19.13	74	2	500	Pass	17.92	4	
AE305	A - 5	0874A	WX1P1	NX1P1	Closed			12.07	375	1	200	Pass	X	7.92	192	4	500	Pass	10.93	4	
BE306	A - 5	0674A	WX1P1	NX1P1	Closed			12.05	305	6	200	Pass	X	20.29	65	3	500	Pass	20.50	4	
DE307	A - 5	0874A	WX1P1	NX1P1	Open	WX1P4	NX1P4	112.06	296	5	200	Pass	X	10.81	41	5	500	Pass	14.07	4	
BH308	A - 10	0674A	WX1P1	NX1P1	Closed			9.86	267	1	200	Pass	X	5.42	34	3	500	Pass	3.38	4	
DH309	A - 10	0974A	WX1P1	NX1P1	Closed			1.98	202	2	200	Pass	X	6.94	31	3	500	Pass	2.25	4	
EH184	B - 1	0575A	WX1P1	NX1P1	Closed			6.72	212	3	200	Pass	X	3.13	51	2	500	Pass	2.01	4	
FH188	B - 5	1173A	WX1P1	NX1P1	Closed			13.07												2	
FH189	B - 10	0873A	WX1P1	NX1P1	Closed			7.08	250	5	200	Pass	X	2.35	49	3	500	Pass	2.24	4	
FE190	B - 5	1173A	WX1P1	NX1P1	Closed			13.41	397	0	200	Pass	X	24.92	53	4	500	Pass	97.72	4	
EE191	G - 5	7350	WX1P1	NX1P1	Closed			12.36	257	3	200	Fail								4	BX1P8
EB192	B - 1	1268A	WX1P1	NX1P1	Closed			182.34	375	1	200	Pass	X	176.48	56	3	500	Pass	169.72	4	
GD198	B - 3	0369A	WX1P1	NX1P1	Open	WX1P4	NX1P4	21.66	243	3	200	Pass	X	27.59	1644	2	500	Pass	17.40	4	
GB199	B - 1	1087A	WX1P1	NX1P1	Closed			180.36												2	
GE200	G - 5	7349	WX1P1	NX1P1	Closed			12.28	214	3	200	Fail								4	BX1P8
HD213	B - 3	0569A	WX1P1	NX1P1	Open	WX1P4	NX1P4	Failed									500			1	BX1P8
HE217	B - 5	1173A	WX1P1	NX1P1	Closed			13.45	219	1	200	Pass	X	21.73	66	3	500	Pass	8.53	4	

			Failure Analysis (8) and (14)						Retest Failed Cal.Test (perform test that failed originally)								
Block Number (#)	Manufacturer		If Failure: Prior to Cycling breaker	Cycle breaker once and retest	breaker 2nd time and retest.	breaker 3rd time and retest.	breaker 4th time and retest.	breaker 5th time and retest.	200% Overload (s)			500% Overload (s)			Send CB to manufacturer		
Sample Number	Part Designator	Date Code	LVCR (mV)	LVCR (mV)	LVCR (mV)	LVCR (mV)	LVCR (mV)	LVCR (mV)	LVCR Max (mV)	Temp. Rise (°C)	P/F ?	LVCR Max (mV)	Temp Rise (°C)	P/F ?	Date Sent	Manf. FA #	Date Returned
AD001	A - 3	0974A															
AD002	A - 3	0974A															
AE007	A - 5	1091A															
AE008	A - 5	0792A															
AH012	A - 10	0974A															
BA020	L - .5	7207															
BA021	L - .5	8203															
BD027	A - 3	0374A															
BD028	A - 3	0874A															
BD029	A - 3	0374A															
BE039	A - 5	0674A															
BE040	A - 5	0674A															
BH045	A - 10	0674A															
BH046	A - 10	0674A															
BH047	A - 10	0674A															
CD066	A - 3	0874A															
CD067	B - 3	0489A															
CD068	B - 3	0887A															
CE079	A - 5	0289A															
CH084	H - 10	7807															
DA091	L - .5	9346															
DA092	L - .5	7417															
DA093	L - .5	7425															
DA094	L - .5	7408															
DA095	L - .5	7439															
DE116	A - 5	0874A															
DE117	A - 5	0874A															
DE118	A - 5	0996															
DH137	A - 10	1274A															
DH138	A - 10	0974A															
BD303	A - 3	0374A															
CD304	B - 3	9138															
AE305	A - 5	0874A															
BE306	A - 5	0674A															
DE307	A - 5	0874A															
BH308	A - 10	0674A															
DH309	A - 10	0974A															
EH184	B - 1	0575A															
FH188	B - 5	1173A															
FH189	B - 10	0873A															
FE190	B - 5	1173A															
EE191	G - 5	7350	8.04	7.97	7.93	7.92	8.57	8.94	168	1	Fail				9/6/01		
EB192	B - 1	1268A															
GD198	B - 3	0369A															
GB199	B - 1	1087A															
GE200	G - 5	7349	13.18	9.17	8.72	8.51	12.07	15.45	135	2	Fail				9/6/01		
HD213	B - 3	0569A	0.00	0.00	0.00	0.00	0.00	0.00							9/6/01		
HE217	B - 5	1173A															

Block Number (#)	Manufacturer		Visual (See Inventory Sheet) & X-Ray Photo # (1)		(2)	Open Breakers only: Close & X-Ray Photo # (3) (4)		(5)	150% or 200% Overload Cal. (6)				(10)	(11)	400%, 500% or 600% Overload Cal. (12)				(16)	Comments Provided below	X-Ray Button View
Sample Number	Part Designator	Date Code	Sample#-Wide View	Sample#-Narrow View	Breaker Open/ Closed	Sample#-Wide View	Sample#-Narrow View	L.V.C.R. Avg (mV)	LVCR Max (mV)	Temp. Rise (°C)	Overload %	P/F ? (7)	Close Breaker	L.V.C.R. Avg (mV)	LVCR Max (mV)	Temp. Rise (°C)	Overload %	P/F ? (13)	L.V.C.R. Avg (mV)	(1,2, etc)	Sample#-Button
HH221	B - 10	0873A	WX1P1	NX1P1	Open	WX1P4	NX1P4	7.12	205	7	200	Pass	X	2.48	85	1	500	Pass	2.30	4	
IB230	B - 1	1168A	WX1P1	NX1P1	Closed			179.97												2	
IB231	K - 1	9043	WX1P1	NX1P1	Closed			149.2	419	4	200	Pass	X	172.48	577	2	500	Pass	236.56	4	
IB232	B - 1	9128	WX1P1	NX1P1	Closed			178.65	458	3	200	Pass	X	170.27	81	4	500	Pass	178.74	4	
ID237	B - 3	0569A	WX1P1	NX1P1	Closed			22.03												2	
JD244	J - 3	7333	WX1P1	NX1P1	Closed			53.72												2	
JD245	B - 3	0673A	WX1P1	NX1P1	Closed			22.06	274	4	200	Pass	X	49.99	282	1	500	Pass	33.71	4	
JE253	B - 5	1268A	WX1P1	NX1P1	Closed			14.05	260	2	200	Pass	X	13.80	135	4	500	Pass	15.66	4	
JH255	G - 10	8045	WX1P1	NX1P1	Closed			7.79												2	
KD258	B - 3	1083A	WX1P1	NX1P1	Closed			10.85	245	4	200	Pass	X	16.36	43	1	500	Pass	18.97	4	
KD259	B - 3	0369A	WX1P1	NX1P1	Closed			10.66	249	4	200	Pass	X	17.36	96	3	500	Pass	17.08	4	
KE262	G - 5	7350	WX1P1	NX1P1	Closed			5.93												2	
KH265	B - 10	0373A	WX1P1	NX1P1	Closed			9.12	221	7	200	Pass	X	121.07	76	3	500	Pass	51.44	4	
KH266	B - 10	0973A	WX1P1	NX1P1	Closed			7.46												2	
LB270	B - 1	0569A	WX1P1	NX1P1	Closed			178.31	421	4	200	Pass	X	208.45	12	5	500	Pass	221.40	4	
LD279	B - 3	0569A	WX1P1	NX1P1	Closed			8.33	363	2	200	Pass	X	20.60	48	4	500	Pass	15.86	4	
LE281	B - 5	1173A	WX1P1	NX1P1	Closed			8.65												2	
LE282	B - 5	1173A	WX1P1	NX1P1	Open	WX1P4	NX1P4	7.93	236	2	200	Pass	X	10.95	32	3	500	Pass	8.35	4	
LH287	B - 10	0873A	WX1P1	NX1P1	Closed			2.19	273	4	200	Pass	X	11.13	56	4	500	Pass	11.43	4	
GB301	B - 1	1185A	WX1P1	NX1P1	Closed			168.37	466	4	200	Pass	X	168.89	23	4	500	Pass	221.12	4	
IB302	B - 1	0569A	WX1P1	NX1P1	Closed			172.57	440	3	200	Pass	X	182.65	118	5	500	Pass	168.13	4	
ED310	B - 3	0569A	WX1P1	NX1P1	Closed			24.96	282	2	200	Pass	X	20.14	51	4	500	Pass	84.15	4	
JD311	B - 3	0973A	WX1P1	NX1P1	Closed			21.75	262	2	200	Pass	X	111.82	44	4	500	Pass	17.36	4	
EE312	B - 5	1173A	WX1P1	NX1P1	Closed			264.23	0	0	200	Fail								5	BX1P8
LE313	B - 5	1173A	WX1P1	NX1P1	Closed			36.59	204	3	200	Pass	X	13.94	39	3	500	Pass	11.61	4	
JH314	B - 10	1273A	WX1P1	NX1P1	Closed			30.9	241	5	200	Pass	X	3.06	49	4	500	Pass	96.56	4	
KH315	B - 10	0973A	WX1P1	NX1P1	Closed			3.61	232	5	200	Pass	X	44.19	34	3	500	Pass	3.02	4	

Notes:

1. Circuit breaker would not stay mechanically closed.
2. Circuit breakers removed from test due to initial current surges during LVCR test.
3. Circuit breaker has no higher percent overload requirement
4. Circuit breaker exposed to current surges during initial LVCR test.
5. LVCR value, during 200% repeat test, exceeded reading capability of the test equipment

F-4

Block Number (#)	Manufacturer		If Failure: Prior to Cycling breaker	Cycle breaker once and retest	breaker 2nd time and retest.	breaker 3rd time and retest.	breaker 4th time and retest.	breaker 5th time and retest.	200% Overload (s)			500% Overload (s)			Send CB to manufacturer		
Sample Number	Part Designator	Date Code	LVCR (mV)	LVCR (mV)	LVCR (mV)	LVCR (mV)	LVCR (mV)	LVCR (mV)	LVCR Max (mV)	Temp. Rise (°C)	P/F ?	LVCR Max (mV)	Temp Rise (°C)	P/F ?	Date Sent	Manf. FA #	Date Returned
HH221	B - 10	0873A															
IB230	B - 1	1168A															
IB231	K - 1	9043															
IB232	B - 1	9128															
ID237	B - 3	0569A															
JD244	J - 3	7333															
JD245	B - 3	0673A															
JE253	B - 5	1268A															
JH255	G - 10	8045															
KD258	B - 3	1083A															
KD259	B - 3	0369A															
KE262	G - 5	7350															
KH265	B - 10	0373A															
KH266	B - 10	0973A															
LB270	B - 1	0569A															
LD279	B - 3	0569A															
LE281	B - 5	1173A															
LE282	B - 5	1173A															
LH287	B - 10	0873A															
GB301	B - 1	1185A															
IB302	B - 1	0569A															
ED310	B - 3	0569A															
JD311	B - 3	0973A															
EE312	B - 5	1173A	327.78	195.52	302.72	312.14	315.82	317.48	0.00	2	Fail				9/6/01		
LE313	B - 5	1173A															
JH314	B - 10	1273A															
KH315	B - 10	0973A															
Notes:																	
1. Circuit breaker would not stay n																	
2. Circuit breakers removed from t																	
3. Circuit breaker has no higher pe																	
4. Circuit breaker exposed to curre																	
5. LVCR value, during 200% repea																	

F.2 FAILURE ANALYSIS REPORTS.

DATE **9/7/01**	MECHANICAL PRODUCTS FAILURE ANALYSIS REPORT	REPORT # **847**
PART NUMBER **700-013-5**	CUSTOMER **FAA - RAYTHEON TECHNICAL SERVICES**	S/N **GE200**
PART NAME **CIRCUIT BREAKER**	CUSTOMER PART NUMBER **BACC18R5B**	FILE CODE **ja0907-1.far**
TESTING BY DEPARTMENT **97 & 98**	ANALYSIS AND/OR TEARDOWN BY DEPT. **97**	CORRECTIVE ACTION BY DEPT.

STATEMENT OF DISCREPANCY

One MP P/N 700-013-5 (5 amp), BACC18R5B circuit breaker, stamped with a date code of the 49th week of 1973, was returned to Mechanical Products for analysis on 9/6/01 by Ron Peterson, Raytheon Technical Services, as part of the ongoing Federal Aviation Administration's "Evaluation of Age Related Degradation of Circuit Breakers" project. This breaker appeared to have been marked on one side with a felt pen as "GE200".

The documentation received at MP pertaining to unit "GE200" (Attachment 1) indicated Raytheon had subjected unit "GE200" to "Test Process Number 1" of the FAA's "Research Plan for the Evaluation of Age Related Degradation of Single and Three Phase Circuit Breakers" (Attachment 2). This documentation listed "GE200" as having been subjected to the "Low Voltage Contact Resistance Test" with an average voltage drop (over five runs) of 10.33 mV at 200 mA. It also listed "GE200" as having been subjected to the "Repeat 200% Overload Calibration Test" with a "Maximum Voltage Drop" of 135 mV, a "Maximum Temperature Rise" of 2°C, and an "Actual Trip Time" of 13.9 seconds. The "Results" column listed the unit as "fail", presumably based on the 13.9 sec. trip time being below the 15 second minimum specification limit (previously provided to Raytheon by Mechanical Products, based on Boeing Part Standard BACC18R5B).

ANALYSIS

Visual Examination

The breaker was externally examined. There was both terminal and mounting hardware attached to the breaker, presumably the hardware that was used in the aircraft application. Mechanical Products' Final Inspection and Functional Test department stamps were visible on the breaker case. These stamps, as well as the original part number stamping, Mechanical Products name, and the felt pen ID applied prior to receipt by MP are shown in the photographs of Figure 1.

It was noted that the external surfaces of the breaker were very clean (as compared to others field units of similar age which have been examined by MP). However, the ampere rating on the button ("5") was covered with grime and barely visible. This grime layer also appeared on the top side of the button (with respect to the rating stamp) but did not appear on the trip indicator. The terminals were thinly coated with a black substance, primarily on the screw head side. There was some dust and grime on the terminal screws and a thin layer of gray grime on parts of the case (which could be easily removed). The mounting bushing was a dark metallic gray color (rather than black).

Radiographs were taken in the "open" condition as received (Figure 2). No anomalies were noted.

"Block 8" Testing

The breaker was then tested according to the requirements of "Block 8 - Failure Analysis (200% Overload Calibration)" of the FAA's "Research Plan for ... Circuit Breakers". During the first on/off cycle radiographs were taken of the breaker in the "closed" condition (Figure 3). The low voltage contact resistance measurements were as follows:

8.2 mV	(taken prior to cycling)
9.1	(after first cycle)
8.5	(after second cycle)
8.8	(after third cycle)
8.4	(after fourth cycle)
8.7	(after fifth cycle)

The 200% overload test results were as follows:

200% trip time (sec.)	Max. voltage drop (mV)	Terminal temperature rise (°C)
19.6	365	2

Dielectric Test

The dielectric tests of MIL-C-5809, paragraph 4.7.2 were performed with the following results (1500VAC for 1 minute):

		Leakage
CB open:	Line terminal to Load terminal	3 uA
	Line terminal to mounting sleeve	3 uA
	Load terminal to mounting sleeve	4 uA
CB closed:	Line/load terminals to mounting	4 uA

These values are within specification and well below the maximum specification of 1 mA. There was no evidence of breakdown, flashover or arcing.

Operating Force

The operating force tests of MIL-C-5809, paragraph 4.7.6 were performed 3 times with the following results:

Pullout	Reset	
4.2	5.9	pounds
4.1	5.9	
3.9	5.8	

These values are within specification (2 to 8 pounds pullout and 4 to 12 pounds reset).

Voltage Drop

The voltage drop across the breaker was measured three times at 100% of rated current per MIL-C-5809, paragraph 4.7.19 with the following results:

Voltage Drop	
183	mV
195	
207	

Although there are no maximum voltage drop limits specified for a BACC18R5B breaker, the results of this test are well within the 0.250 volt maximum specified for a 5 amp rated MS25244 breaker (MP 700-001-5).

200% Overload, Min/Max Ultimate Trip

Five 200% overload trip tests were performed per MIL-C-5809, paragraph 4.7.7.3; five 138% maximum limit of ultimate trip tests were performed per MIL-C-5809, paragraph 4.7.7.2; and five 115% minimum limit of ultimate trip tests (breaker must hold closed) were performed per MIL-C-5809, paragraph 4.7.7.1 with following results (time in seconds):

200%	138%	115%
19.7	111	NT
17.6	113	646
16.6	162	NT
19.7	176	NT
16.9	143	NT

(Note: "NT" indicates breaker did not trip during test; for the 115% hold tests temperature monitoring was not performed)

All tests results are within specification with the exception of the second 115% hold test. The specification requires the breaker to hold closed without tripping for the duration of the 115% minimum limit of ultimate trip test; the breaker tripped 646 seconds into that test.

Internal Examination

The breaker was disassembled and examined. There were a small number of tiny black flakes loose within the case cavity. The contacts showed slight surface damage and there was minor discoloration of the case near the contacts, consistent with the breaker having been cycled under load or having tripped under overloads of less than short circuit conditions. There was some wear to the electrical (bimetal) latch. There was a normal amount of lubricant present on the button latch rollers. No obvious anomalies were noted.

Due to time constraints imposed for submission of this report, additional testing and analysis were not performed.

CONCLUSIONS

The low voltage contact resistance, voltage drop, operating force, 200% overload trip, and 138% trip test results were all within specified limits. The results were all very similar to results of tests on 5 amp MP 700 Series circuit breakers built within the year 2001. All tests were performed to the requirements of MIL-C-5809 and BACC18R unless otherwise noted.

The field history of the breaker identified as "GE200" was not available at the time of this analysis.

The 200% overload trip test performed at Raytheon may have been the first time this breaker was required to open a circuit in response to an overload condition since it left Mechanical Products approximately 28 years ago. The number of manual cycles since initial installation also was not known.

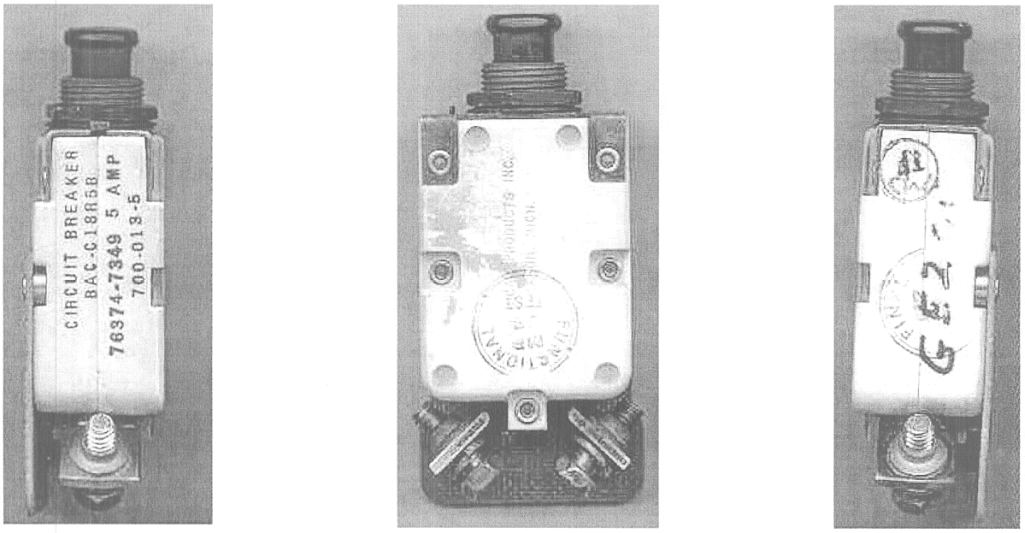
The 200% overload trip time experienced at Raytheon was only 1.1 seconds under the specified 15 second minimum (less than 3% of the allowable 15 to 55 second trip range). Multiple 200% overload tests at Mechanical Products did not repeat the failure seen at Raytheon. The breaker also passed five 138% maximum ultimate trip tests and four 115% minimum ultimate trip tests at Mechanical Products. There was one failure to hold closed at 115% for the required time period.

Examination of the internal mechanism did not appear to indicate the breaker had been electrically or manually cycled much beyond the endurance limits specified in BACC18R. There were no indications that the breaker had been exposed to high current interruption or severe contamination.

The additional testing without failures indicates this breaker is probably very close to being completely within specification. The single 115% hold failure and the slightly low 200% trip time during the Raytheon testing could indicate a very slight downward shift in electrical calibration over time. A calibration shift of this type could be the result of slight wear to the electrical latch over a number of years of manual cycling. The failures could also be the result of not having exercised the electrical trip portion of the mechanism in a very long time. As noted previously, the functional history of this breaker during the approximately 28 years since it left Mechanical Products was not available.

CORRECTIVE ACTION

None requested or required.



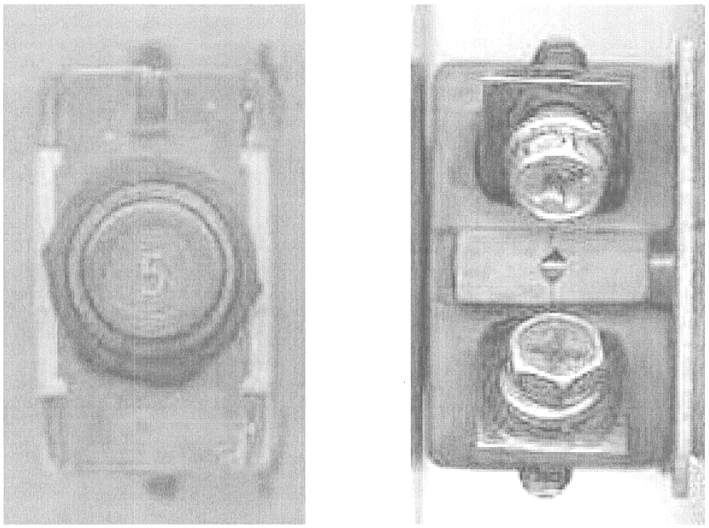


Figure 1.
Exterior of circuit breaker "GE200".

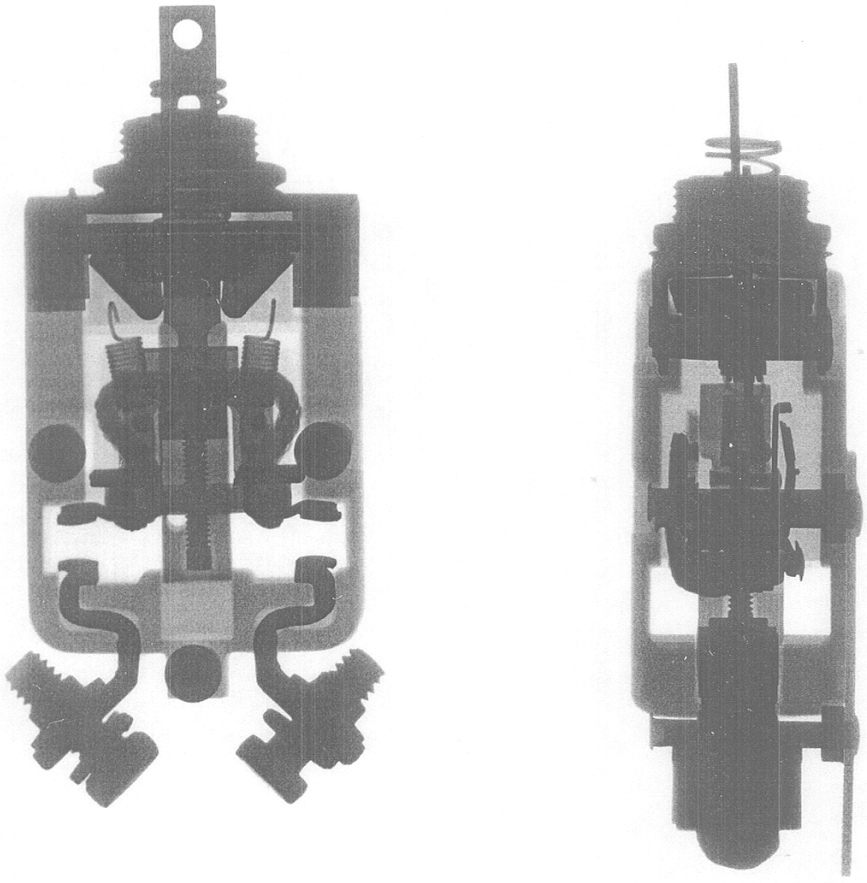


Figure 2.
Radiograph of breaker "GE200" in the open (unlatched) position as received.

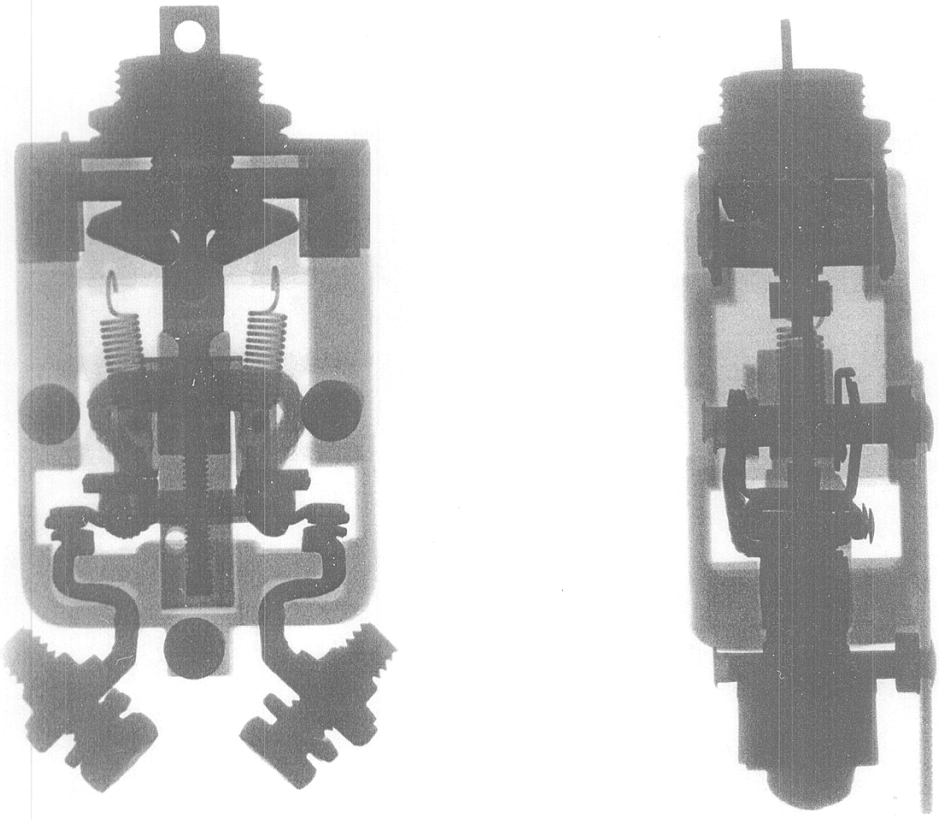


Figure 3.
Radiograph of breaker "GE200" in the closed (latched) position.

Attachment 1

Documentation received for sample "GE200"

Date: 9/5/01

To: Mechanical Products Inc.
Attn: James C. Allison
1824 River Street
Jackson, MI 49202

From: Raytheon Technical Services Company
Attn: Ronnie Peterson, M/S 37
6125 East 21ST Street
Indianapolis, IN 46219-2058

In-closed are the failed samples that occurred during our FAA testing on circuit breakers that came from aged aircraft.

You are requested to perform a failure analysis on the breakers per your agreement with the FAA representative Mr. Rob Pappas.

Please send your report by 9/12/01, so that it can be added to the FAA report to be provided by RTSC.

Please provide a separate report for each failure and designate your report by the number specified for the sample.

Regards

Ron

RAYTHEON TECHNICAL SERVICES COMPANY
INTERCONNECTIONS ENGINEERING
TEST LABORATORY DATA SHEET

Sample Number	Obser-vation Notes	Report Number	x-ray wide & narrow Provid	X-ray Button View Provid	Repeat Test Compte	LVCR Info Sent	Date Sent	Date Recv	Shipping Information
HD213	1	HD213P1B5			*	*			
EE312		EE312P1B6	V	✓	✓	✓	9/5		
EE191		EE191P1B6	✓	✓	✓	✓	9/5		
GE200		GE200P1B6			✓				

OBSERVATIONS: 1* CANNOT PERFORM LVCR, BREAKER WILL NOT STAY CLOSED. Notice Problem at block 5

Page _____

RAYTHEON TECHNICAL SERVICES COMPANY
INTERCONNECTIONS ENGINEERING
LABORATORY TEST DATA SHEET

Test Low Voltage Contact Resistance	Project Number 50-20-011	Date 8/30/01	Tested By GSA
Test Equipment H/P 6034A H/P 6032A Keithley 197 Keithley 197	Calibration Number 36529 40568 35205	Calibration Due 1/9/04 12/22/02 12/22/02	Specification FAA & MIL-C-5809
Process #: 1 Block #: 8	Test Temperature: 24C Soak Temperature: 24C	Test Paragraphs: Met: 4.7.17.1 & FAA Test Plan	Test Parameters Voltage (Open Circuit Volts DC): 26 ±2V

	cycle 1	cycle 2	cycle 3	MEASURED VOLTAGE DROP (mV)								CURRENT
SAMPLE NUMBER	READING #1	READING #2	READING #3	READING #4	READING #5	READING #6	READING #7	READING #8	READING #9	READING #10	READING AVERAGE	Last Reading (MILLIAMP)
EE312	327.78	195.523	302.72	312.14	315.82							200
EE191	8.043	7.967	7.927	7.915	8.570							200
GE200	13.177	9.169	8.717	8.514	12.073							200
HD213	WILL	NOT	STAY	CLOSED.	(Not tested	Notice Problem at Block 5						)

COMMENTS: _____

_____

TEST PROCEDURE #3008C-FAA DATE(last revised) 9/5/01

RAYTHEON TECHNICAL SERVICES COMPANY
INTERCONNECTIONS ENGINEERING
LABORATORY TEST DATA SHEET

	Project Number 50-20-011	Date 9/5/01	Tested By [signature]
Test Equipment Munro Q/C-20 Omega OM-400	Calibration Number 45585 39650	Calibration Due 1/8/02 8/20/02	Specification MIL-C-5809
Test Repeat 200% Overload Calibration	Test Paragraphs Req: 3.7.4 Met: 4.7.4.3		Test Process #: 1 Process Block #: 8 Ambient Temp: 26°C

SAMPLE NUMBER	CURRENT RATING (A)	MAX VOLTAGE DROP (MV)	MAX TEMP RISE (C)	REQUIRED TRIP TIME (S)	ACTUAL TRIP TIME (S)	RESULTS PASS/ FAIL
EE191	5	168	1	15-55	13.5	FAIL
GE200	5	135	2	15-55	13.9	FAIL
E ~~[illegible]~~312 ~~[illegible]~~	3	0	2	~~[illegible]~~ 2-20	0	FAIL

COMMENTS: _____

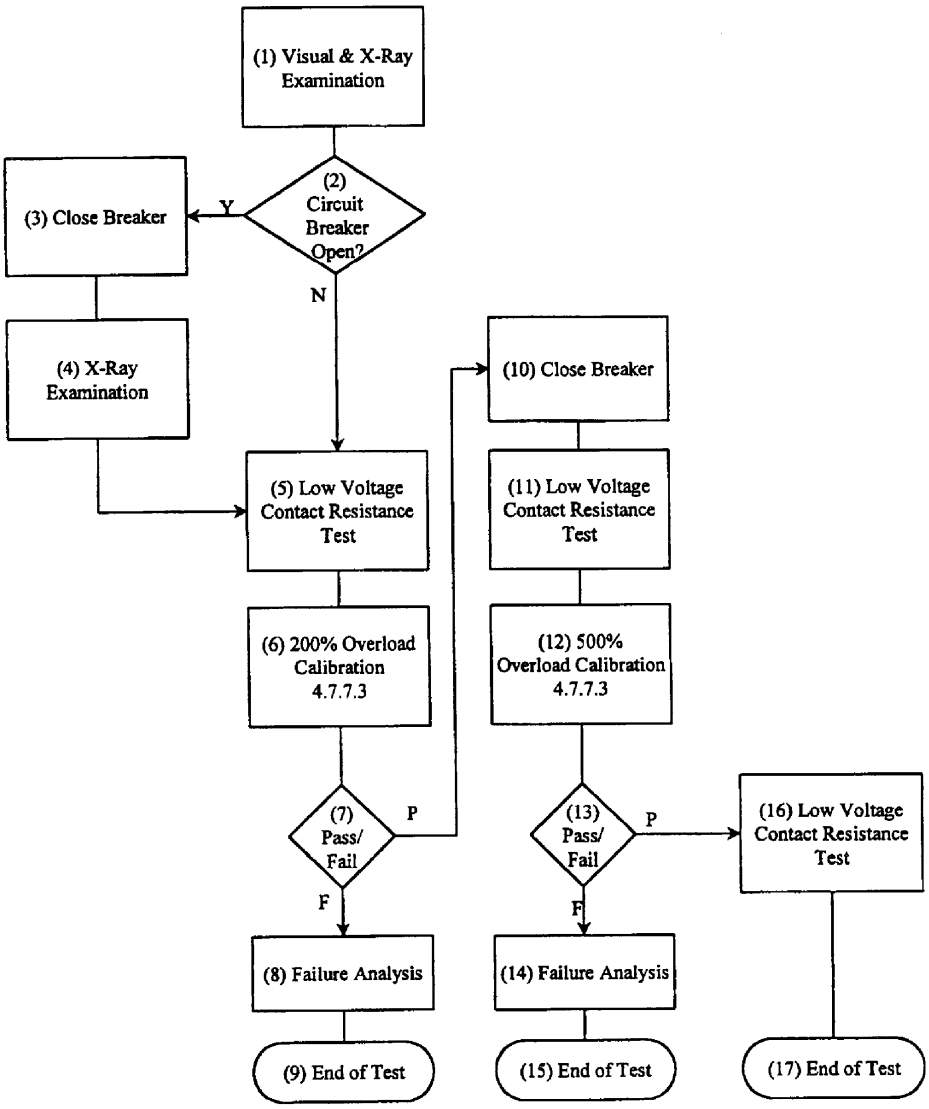
Page

Attachment 2

"Test Process Number 1"

from

FAA
"Research Plan for the
Evaluation of Age Related Degradation
of Single and Three Phase Circuit Breakers"


(1) Visual & X-Ray Examination
(2) Circuit Breaker Open?
Y
(3) Close Breaker
N
(4) X-Ray Examination
(5) Low Voltage Contact Resistance Test
(6) 200% Overload Calibration 4.7.7.3
(7) Pass/ Fail
P
F
(8) Failure Analysis
(9) End of Test
(10) Close Breaker
(11) Low Voltage Contact Resistance Test
(12) 500% Overload Calibration 4.7.7.3
(13) Pass/ Fail
P
F
(14) Failure Analysis
(15) End of Test
(16) Low Voltage Contact Resistance Test
(17) End of Test

TEST PROCESS NUMBER 1 FLOWCHART BLOCK DEFINITIONS

The chart above contains the Test Process Number 1 Flowchart. The flowchart illustrates the sequence of tests to be performed on the breakers designated for test. Each block in the flowchart is numbered. Complete descriptions of each block are provided below. To avoid repetition, blocks containing the same process are grouped together.

Block 1: **Visual & X-Ray Examination**

MIL-C-5809 Test Number: NA

Special Instructions: Each circuit breaker shall be examined visually and radiographically to record the initial condition of the breaker. Each sample will be x-rayed once in each axis. Check with OEM possible circuit breaker type specific x-ray requirements.

Block 2: **Circuit Breaker Open (Y/N)**

MIL-C-5809 Test Number: NA

Special Instructions: Record the state of the circuit breaker as either OPEN or CLOSED. If OPEN proceed to block 3. If CLOSED proceed to block 5. Do not change the state of the breaker.

Block 3, 10: **Close Breaker**

MIL-C-5809 Test Number:

Special Instructions: Breaker shall only be closed once. DO NOT cycle the breaker.

Block 4: **X-Ray Examination**

MIL-C-5809 Test Number:

Special Instructions: Generally, each sample will be x-rayed once in each axis. Check with OEM possible circuit breaker type specific x-ray requirements.

Block 5, 11, 16: **Low Voltage Contact Resistance Test**

MIL-C-5809 Test Number: 4.7.17.1 (see special instructions)
Special Instructions: 4.7.17.1 is normally performed in conjunction with Moisture Resistance tests (4.7.17). Moisture resistance is not part of this evaluation. However, the low voltage contact resistance measurement procedures described in 4.7.17.1 will be followed with the following deviations. Each CB will be operated in a circuit containing a dc resistive load of 200 milliamps at 26 ±2 volts. In series with the load shall be a manually operated switch (not the CB) to control power on/off. The contact resistance (specified as millivolt drop) shall be computed by averaging the result of 10 measurements. Each measurement shall be taken after a consecutive switch closure. All measurements shall be made across the CB external electrical terminals. (Note: The circuit breaker shall not be exercised on/off during this test) Soak (no load) at ambient for one-hour minimum before test.

Block 6: **200% Overload Calibration**

MIL-C-5809 Test Number: 4.7.7.3
Special Instructions: Test at 200% of rated current only. Do not test at higher currents. Soak (no load) at ambient for one-hour minimum before test, breaker in the open position, if possible. Do not open the breaker if it is already in a closed position. Voltage drop from circuit breaker terminal-to-terminal will be monitored at all times. The temperature rise of the breaker terminals shall be obtained by the use of a suitable thermocouple.

Block 7: **Pass/fail (200% Overload Calibration)**

MIL-C-5809 Test Number: 4.7.7.3

Special Instructions: NA

Block 8: **Failure Analysis (200% Overload Calibration)**

MIL-C-5809 Test Number: 4.7.7.3

Special Instructions: As the first step in the failure analysis, the OEM will repeat test 6 after the breaker has been cycled off/on five times with no power applied. A low voltage contact resistance measurement will be obtained before the first and after each of the five-off/on cycles. After the cycling process is complete, test 55 will be repeated. Regardless of the outcome of this test, a failure analysis will be performed to determine the cause of the first failure or both failures as applicable. The failure analysis will be conducted by the circuit breaker OEM. The OEM will follow approved, company standard operating procedures (SOP) to conduct the analysis. When the SOP is inadequate for the complete determination of the failure or degradation causal factors, it shall be supplemented with additional procedures necessary to do so. For example, such procedures might include chemical analysis, optical microscopy, electron microscopy, and others.

Block 12: **500% Overload Calibration**

MIL-C-5809 Test Number: 4.7.7.3
Special Instructions: Test at 500% of rated current only. Do not test at higher currents. Soak (no load) at ambient for one-hour minimum before test, breaker in the open position, if possible. Do not open the breaker if it is already in a closed position. Voltage drop from circuit breaker terminal-to-terminal will be monitored at all times. The temperature rise of the breaker terminals shall be obtained by the use of a suitable thermocouple.

Block 13: **Pass/fail (500% Overload Calibration)**

MIL-C-5809 Test Number: 4.7.7.3

Special Instructions: NA

Block 14: **Failure Analysis (500% Overload Calibration)**

MIL-C-5809 Test Number: 4.7.7.3

Special Instructions: As the first step in the failure analysis, the OEM will repeat test 59 after the breaker has been cycled off/on five times with no power applied. A low voltage contact resistance measurement will be obtained before the first and after

each of the five-off/on cycles. After the cycling process is complete, test 59 will be repeated. Regardless of the outcome of this test, a failure analysis will be performed to determine the cause of the first failure or both failures as applicable. The failure analysis will be conducted by the circuit breaker OEM. The OEM will follow approved, company standard operating procedures (SOP) to conduct the analysis. When the SOP is inadequate for the complete determination of the failure or degradation causal factors, it shall be supplemented with additional procedures necessary to do so. For example, such procedures might include chemical analysis, optical microscopy, electron microscopy, and others.

Block 17: **End of Test**

MIL-C-5809 Test Number: NA

Special Instructions: Safely store the CB in a suitable container that will protect the CB from physical or chemical damage. Insure that the breaker is properly labeled. Store the CB in its end of test state. Do not close or open the CB switch, or manipulate the CB in any way. If the circuit breaker has been disassembled, collect and properly store all remaining parts.

DATE **9/7/01**	MECHANICAL PRODUCTS FAILURE ANALYSIS REPORT	REPORT # **848**
PART NUMBER **700-013-5**	CUSTOMER **FAA - RAYTHEON TECHNICAL SERVICES**	S/N **EE191**
PART NAME **CIRCUIT BREAKER**	CUSTOMER PART NUMBER **BACC18R5B**	FILE CODE **ja0907-3.far**
TESTING BY DEPARTMENT **97 & 98**	ANALYSIS AND/OR TEARDOWN BY DEPT. **97**	CORRECTIVE ACTION BY DEPT.

STATEMENT OF DISCREPANCY

One MP P/N 700-013-5 (5 amp), BACC18R5B circuit breaker, stamped with a date code of the 50th week of 1973, was returned to Mechanical Products for analysis on 9/6/01 by Ron Peterson, Raytheon Technical Services, as part of the ongoing Federal Aviation Administration's "Evaluation of Age Related Degradation of Circuit Breakers" project. This breaker appeared to have been marked on one side with a felt pen as "EE191".

The documentation received at MP pertaining to unit "EE191" (Attachment 1) indicated Raytheon had subjected unit "EE191" to "Test Process Number 1" of the FAA's "Research Plan for the Evaluation of Age Related Degradation of Single and Three Phase Circuit Breakers" (Attachment 2). This documentation listed "EE191" as having been subjected to the "Low Voltage Contact Resistance Test" with an average voltage drop (over five runs) of 8.08 mV at 200 mA. It also listed "EE191" as having been subjected to the "Repeat 200% Overload Calibration Test" with a "Maximum Voltage Drop" of 168 mV, a "Maximum Temperature Rise" of 1°C, and an "Actual Trip Time" of 13.5 seconds. The "Results" column listed the unit as "fail", presumably based on the 13.5 sec. trip time being below the 15 second minimum specification limit (previously provided to Raytheon by Mechanical Products, based on Boeing Part Standard BACC18R5B).

ANALYSIS

Visual Examination

The breaker was externally examined. There was both terminal and mounting hardware attached to the breaker, presumably the hardware that was used in the aircraft application. Mechanical Products' Final Inspection and Functional Test department stamps were visible on the breaker case. These stamps, as well as the original part number stamping, Mechanical Products name, and the felt pen ID applied prior to receipt by MP are shown in the photographs of Figure 1.

It was noted that the external surfaces of the breaker were very clean (as compared to others field units of similar age which have been examined by MP). However, the ampere rating on the button ("5") was covered with grime and barely visible. This grime layer also appeared on the top side of the button (with respect to the rating stamp) but did not appear on the trip indicator. The terminals were thinly coated with a black substance, primarily on the screw head side. There was some dust and grime on the terminal screws and a thin layer of gray grime on parts of the case (which could be easily removed). The mounting bushing was a dark metallic gray color (rather than black).

Radiographs were taken in the "open" condition as received (Figure 2). No anomalies were noted.

"Block 8" Testing

The breaker was then tested according to the requirements of "Block 8 - Failure Analysis (200% Overload Calibration)" of the FAA's "Research Plan for ... Circuit Breakers". During the first on/off cycle radiographs were taken of the breaker in the "closed" condition (Figure 3). The low voltage contact resistance measurements were as follows:

12.9 mV	(taken prior to cycling)
11.1	(after first cycle)
18.9	(after second cycle)
26.5	(after third cycle)
13.8	(after fourth cycle)
27.5	(after fifth cycle)

The 200% overload test results were as follows:

200% trip time (sec.)	Max. voltage drop (mV)	Terminal temperature rise (°C)
16.3	408	3

Dielectric Test

The dielectric tests of MIL-C-5809, paragraph 4.7.2 were performed with the following results (1500VAC for 1 minute):

		Leakage
CB open:	Line terminal to Load terminal	2 uA
	Line terminal to mounting sleeve	4 uA
	Load terminal to mounting sleeve	3 uA
CB closed:	Line/load terminals to mounting	5 uA

These values are within specification and well below the maximum specification of 1 mA. There was no evidence of breakdown, flashover or arcing.

Operating Force

The operating force tests of MIL-C-5809, paragraph 4.7.6 were performed 3 times with the following results:

Pullout	Reset	
6.0	6.5	pounds
6.5	7.0	
6.4	6.9	

These values are within specification (2 to 8 pounds pullout and 4 to 12 pounds reset).

Voltage Drop

The voltage drop across the breaker was measured three times at 100% of rated current per MIL-C-5809, paragraph 4.7.19 with the following results:

Voltage Drop	
196	mV
191	
191	

Although there are no maximum voltage drop limits specified for a BACC18R5B breaker, the results of this test are well within the 0.250 volt maximum specified for a 5 amp rated MS25244 breaker (MP 700-001-5).

200% Overload, Min/Max Ultimate Trip

Five 200% overload trip tests were performed per MIL-C-5809, paragraph 4.7.7.3; five 138% maximum limit of ultimate trip tests were performed per MIL-C-5809, paragraph 4.7.7.2; and five 115% minimum limit of ultimate trip tests (breaker must hold closed) were performed per MIL-C-5809, paragraph 4.7.7.1 with following results (time in seconds):

200%	138%	115%
20.8	121	NT
21.5	121	NT
16.7	120	NT
18.6	200	NT
19.7	196	NT

(Note: "NT" indicates breaker did not trip during test; for the 115% hold tests temperature monitoring was not performed)

All tests results are within specification. The specification requires the breaker to hold closed without tripping for the duration of the 115% minimum limit of ultimate trip test.

Internal Examination

The breaker was disassembled and examined. There were a small number of tiny black flakes loose within the case cavity. The contacts showed slight surface damage and there was minor discoloration of the case near the contacts, consistent with the breaker having been cycled under load or having tripped under overloads of less than short circuit conditions. There was some wear to the electrical (bimetal) latch. There was a normal amount of lubricant present on the button latch rollers. No obvious anomalies were noted.

Due to time constraints imposed for submission of this report, additional testing and analysis were not performed.

CONCLUSIONS

The low voltage contact resistance, voltage drop, operating force, 200% overload trip, 138% trip, and 115% hold test results were all within specified limits. The results were all very similar to results of tests on 5 amp MP 700 Series circuit breakers built within the year 2001. All tests were performed to the requirements of MIL-C-5809 and BACC18R unless otherwise noted.

The field history of the breaker identified as "EE191" was not available at the time of this analysis.

The 200% overload trip test performed at Raytheon may have been the first time this breaker was required to open a circuit in response to an overload condition since it left Mechanical Products approximately 28 years ago. The number of manual cycles since initial installation also was not known.

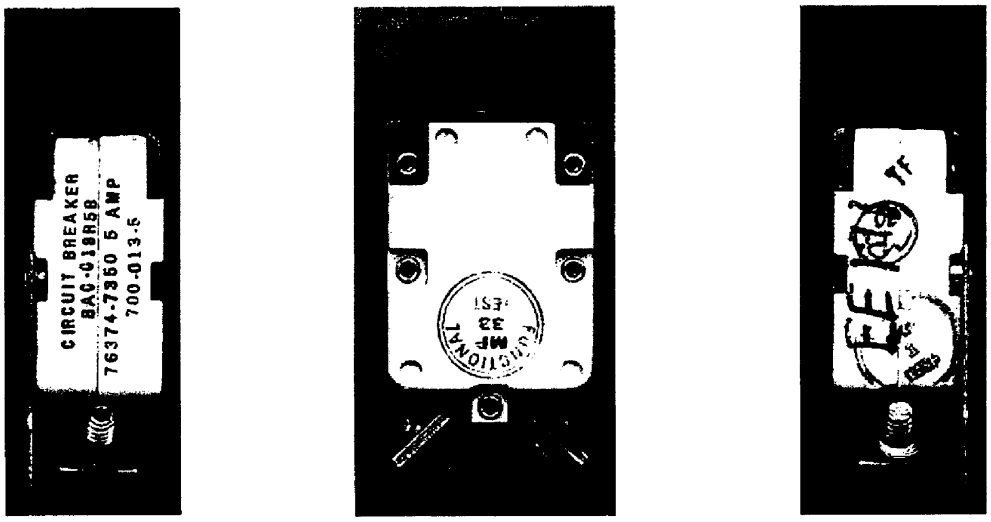
The 200% overload trip time experienced at Raytheon was only 1.5 seconds under the specified 15 second minimum (less than 4% of the allowable 15 to 55 second trip range). Multiple 200% overload tests at Mechanical Products did not repeat the failure seen at Raytheon. The breaker also passed five 138% maximum ultimate trip tests and five 115% minimum ultimate trip tests at Mechanical Products.

Examination of the internal mechanism did not appear to indicate the breaker had been electrically or manually cycled much beyond the endurance limits specified in BACC18R. There were no indications that the breaker had been exposed to high current interruption or severe contamination.

The additional testing without failures indicates this breaker is probably within specification. The slightly low 200% trip time during the Raytheon testing could be the result of not having exercised the electrical trip portion of the mechanism in a very long time. As noted previously, the functional history of this breaker during the approximately 28 years since it left Mechanical Products was not available.

CORRECTIVE ACTION

None requested or required.



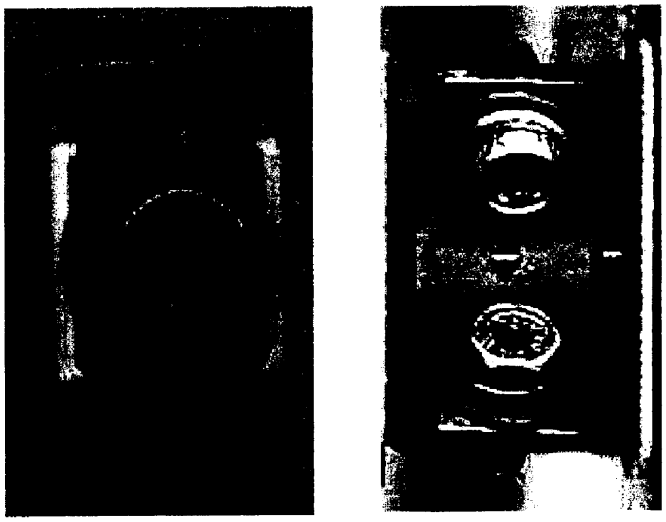


Figure 1.
Exterior of circuit breaker "EE191".

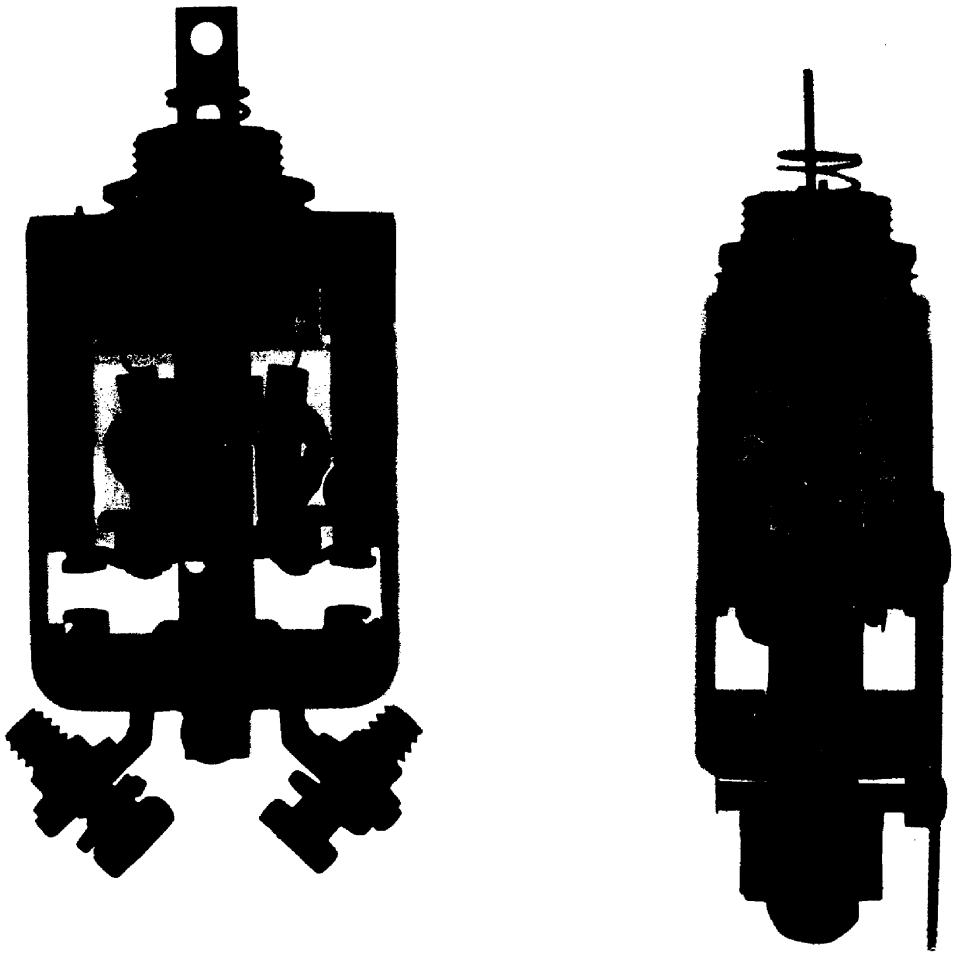


Figure 2.
Radiograph of breaker "EE191" in the open (unlatched) position as received.

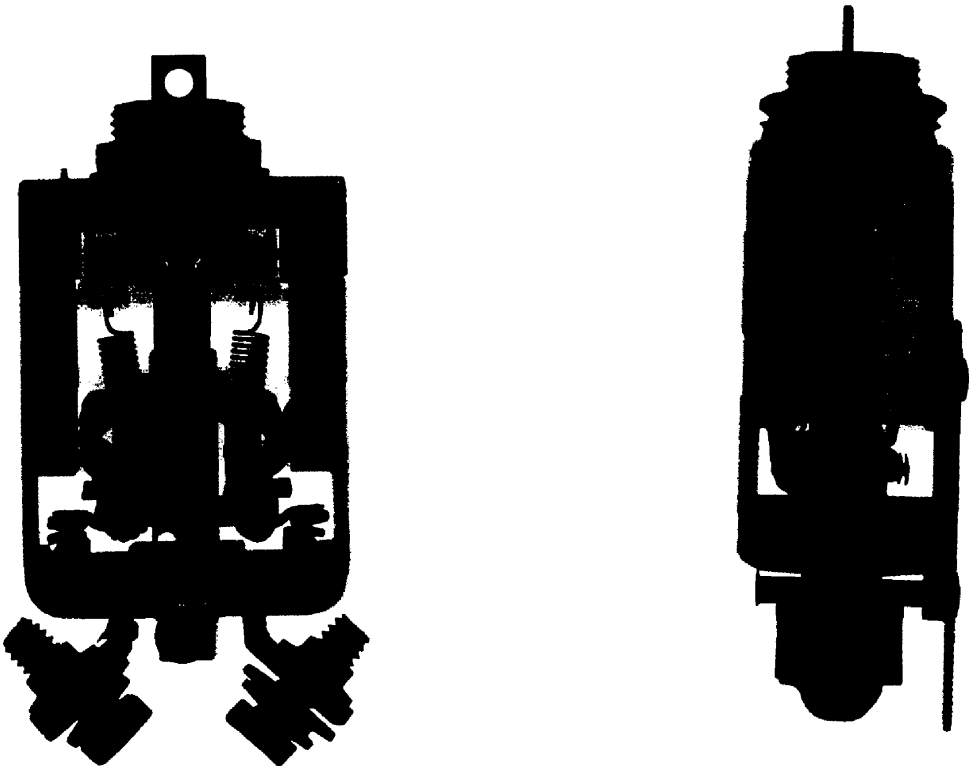


Figure 3.
Radiograph of breaker "EE191" in the closed (latched) position.

Attachment 1

Documentation received for sample "EE191"

Date: 9/5/01

To: Mechanical Products Inc.
Attn: James C. Allison
1824 River Street
Jackson, MI 49202

From: Raytheon Technical Services Company
Attn: Ronnie Peterson, M/S 37
6125 East 21ST Street
Indianapolis, IN 46219-2058

In-closed are the failed samples that occurred during our FAA testing on circuit breakers that came from aged aircraft.

You are requested to perform a failure analysis on the breakers per your agreement with the FAA representative Mr. Rob Pappas.

Please send your report by 9/12/01, so that it can be added to the FAA report to be provided by RTSC.

Please provide a separate report for each failure and designate your report by the number specified for the sample.

Regards

Ron

RAYTHEON TECHNICAL SERVICES COMPANY
INTERCONNECTIONS ENGINEERING
TEST LABORATORY DATA SHEET

Sample Number	Obser-vation Notes	Report Number	x-ray wide & narrow Provid	X-ray Button View Provid	Repeat Test Compte	LVCR Info Sent	Date Sent	Date Recv	Shipping Information
HD213	1	HD213P1B5			*	*			
EE312		EE312P1B6	V	✓	✓	✓	9/5		
EE191		EE191P1B6	✓	✓	✓	✓	9/5		
GE200		GE200P1B6			✓				

OBSERVATIONS: 1* CANNOT PERFORM LVCR, BREAKER WILL NOT STAY CLOSED. Notice Problem at block 5

Page _____

RAYTHEON TECHNICAL SERVICES COMPANY
INTERCONNECTIONS ENGINEERING
LABORATORY TEST DATA SHEET

Test Low Voltage Contact Resistance	Project Number 50-20-011	Date 8/30/01	Tested By GSA
Test Equipment H/P 6034A H/P 6032A Keithley 197 Keithley 197	Calibration Number 36529 40568 35205	Calibration Due 1/9/04 12/22/02 12/22/02	Specification FAA & MIL-C-5809
Process #: 1 Block #: 8	Test Temperature: 24C Soak Temperature: 24C	Test Paragraphs: Met: 4.7.17.1 & FAA Test Plan	Test Parameters Voltage (Open Circuit Volts DC): 26 ±2V

	cycle 1	cycle 2	Cycle 3	MEASURED VOLTAGE DROP (mV)							CURRENT
SAMPLE NUMBER	READING #1	READING #2	READING #3	READING #4	READING #5	READING #6	READING #7	READING #8	READING #9	READING #10	READING AVERAGE	Last Reading (MILLIAMP)
EE312	327.78	195.523	302.72	312.14	315.82							200
EE191	8.043	7.967	7.927	7.915	8.570							200
GE200	13.177	9.169	8.717	8.514	12.073							200
HD213	WILL	NOT	STAY	CLOSED.	(Not tested	Notice Problem at block 5						)

COMMENTS: _____

_____

TEST PROCEDURE #3008C-FAA DATE(last revised) 9/5/01

RAYTHEON TECHNICAL SERVICES COMPANY
INTERCONNECTIONS ENGINEERING
LABORATORY TEST DATA SHEET

	Project Number 50-20-011	Date 9/5/01	Tested By [illegible]
Test Equipment Munro Q/C-20 Omega OM-400	Calibration Number 45585 39650	Calibration Due 1/8/02 8/20/02	Specification MIL-C-5809
Test Repeat 200% Overload Calibration	Test Paragraphs Req: 3.7.4 Met: 4.7.4.3		Test Process #: 1 Process Block #: 8 Ambient Temp: 26°C

SAMPLE NUMBER	CURRENT RATING (A)	MAX VOLTAGE DROP (MV)	MAX TEMP RISE (C)	REQUIRED TRIP TIME (S)	ACTUAL TRIP TIME (S)	RESULTS PASS/ FAIL
EE191	5	168	1	15-55	13.5	FAIL
GE200	5	135	2	15-55	13.9	FAIL
E ~~[illegible]~~312 ~~[illegible]~~	3	0	2	~~[illegible]~~ 5-20	0	FAIL

COMMENTS: _____

Page _____

-WX2P1

↓

LJ316

-BX1P8

↓

EE191



-NX2P1

↓

LJ316

Process 2: (Box 1)

Line 294

-WX1P1

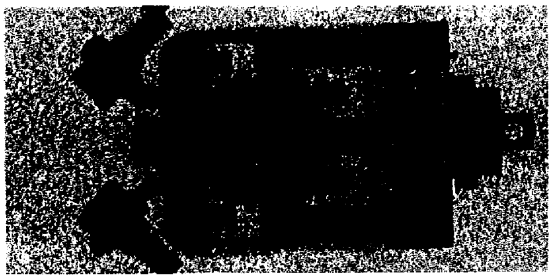
EH184

FE188

FH189

FE190

EE191



-NX1P1

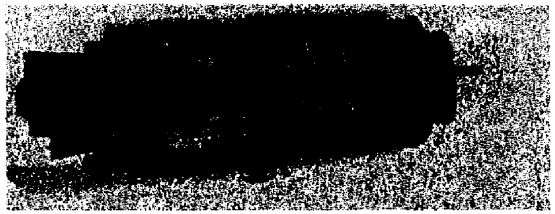
EH184

FE188

FH189

FE190

EE191

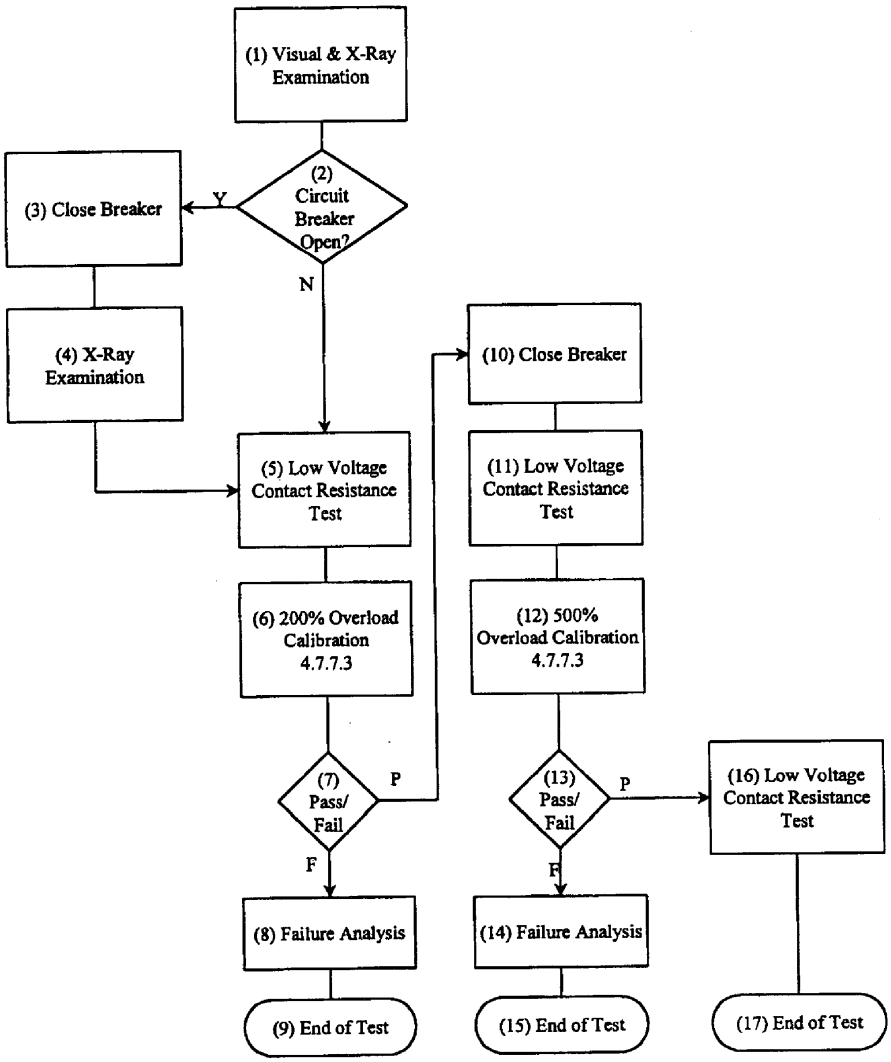


Attachment 2

"Test Process Number 1"

from

FAA
"Research Plan for the
Evaluation of Age Related Degradation
of Single and Three Phase Circuit Breakers"


(1) Visual & X-Ray Examination
(2) Circuit Breaker Open?
Y
(3) Close Breaker
N
(4) X-Ray Examination
(5) Low Voltage Contact Resistance Test
(6) 200% Overload Calibration 4.7.7.3
(7) Pass/ Fail
P
F
(8) Failure Analysis
(9) End of Test
(10) Close Breaker
(11) Low Voltage Contact Resistance Test
(12) 500% Overload Calibration 4.7.7.3
(13) Pass/ Fail
P
F
(14) Failure Analysis
(15) End of Test
(16) Low Voltage Contact Resistance Test
(17) End of Test

TEST PROCESS NUMBER 1 FLOWCHART BLOCK DEFINITIONS

The chart above contains the Test Process Number 1 Flowchart. The flowchart illustrates the sequence of tests to be performed on the breakers designated for test. Each block in the flowchart is numbered. Complete descriptions of each block are provided below. To avoid repetition, blocks containing the same process are grouped together.

Block 1: **Visual & X-Ray Examination**

MIL-C-5809 Test Number: NA

Special Instructions: Each circuit breaker shall be examined visually and radiographically to record the initial condition of the breaker. Each sample will be x-rayed once in each axis. Check with OEM possible circuit breaker type specific x-ray requirements.

Block 2: **Circuit Breaker Open (Y/N)**

MIL-C-5809 Test Number: NA

Special Instructions: Record the state of the circuit breaker as either OPEN or CLOSED. If OPEN proceed to block 3. If CLOSED proceed to block 5. Do not change the state of the breaker.

Block 3, 10: **Close Breaker**

MIL-C-5809 Test Number:

Special Instructions: Breaker shall only be closed once. DO NOT cycle the breaker.

Block 4: **X-Ray Examination**

MIL-C-5809 Test Number:

Special Instructions: Generally, each sample will be x-rayed once in each axis. Check with OEM possible circuit breaker type specific x-ray requirements.

Block 5, 11, 16: **Low Voltage Contact Resistance Test**

MIL-C-5809 Test Number: 4.7.17.1 (see special instructions)
Special Instructions: 4.7.17.1 is normally performed in conjunction with Moisture Resistance tests (4.7.17). Moisture resistance is not part of this evaluation. However, the low voltage contact resistance measurement procedures described in 4.7.17.1 will be followed with the following deviations. Each CB will be operated in a circuit containing a dc resistive load of 200 milliamps at 26 ±2 volts. In series with the load shall be a manually operated switch (not the CB) to control power on/off. The contact resistance (specified as millivolt drop) shall be computed by averaging the result of 10 measurements. Each measurement shall be taken after a consecutive switch closure. All measurements shall be made across the CB external electrical terminals. (Note: The circuit breaker shall not be exercised on/off during this test) Soak (no load) at ambient for one-hour minimum before test.

Block 6: **200% Overload Calibration**

MIL-C-5809 Test Number: 4.7.7.3
Special Instructions: Test at 200% of rated current only. Do not test at higher currents. Soak (no load) at ambient for one-hour minimum before test, breaker in the open position, if possible. Do not open the breaker if it is already in a closed position. Voltage drop from circuit breaker terminal-to-terminal will be monitored at all times. The temperature rise of the breaker terminals shall be obtained by the use of a suitable thermocouple.

Block 7: **Pass/fail (200% Overload Calibration)**

MIL-C-5809 Test Number: 4.7.7.3

Special Instructions: NA

Block 8: **Failure Analysis (200% Overload Calibration)**

MIL-C-5809 Test Number: 4.7.7.3

Special Instructions: As the first step in the failure analysis, the OEM will repeat test 6 after the breaker has been cycled off/on five times with no power applied. A low voltage contact resistance measurement will be obtained before the first and after each of the five-off/on cycles. After the cycling process is complete, test 55 will be repeated. Regardless of the outcome of this test, a failure analysis will be performed to determine the cause of the first failure or both failures as applicable. The failure analysis will be conducted by the circuit breaker OEM. The OEM will follow approved, company standard operating procedures (SOP) to conduct the analysis. When the SOP is inadequate for the complete determination of the failure or degradation causal factors, it shall be supplemented with additional procedures necessary to do so. For example, such procedures might include chemical analysis, optical microscopy, electron microscopy, and others.

Block 12: **500% Overload Calibration**

MIL-C-5809 Test Number: 4.7.7.3
Special Instructions: Test at 500% of rated current only. Do not test at higher currents. Soak (no load) at ambient for one-hour minimum before test, breaker in the open position, if possible. Do not open the breaker if it is already in a closed position. Voltage drop from circuit breaker terminal-to-terminal will be monitored at all times. The temperature rise of the breaker terminals shall be obtained by the use of a suitable thermocouple.

Block 13: **Pass/fail (500% Overload Calibration)**

MIL-C-5809 Test Number: 4.7.7.3

Special Instructions: NA

Block 14: **Failure Analysis (500% Overload Calibration)**

MIL-C-5809 Test Number: 4.7.7.3

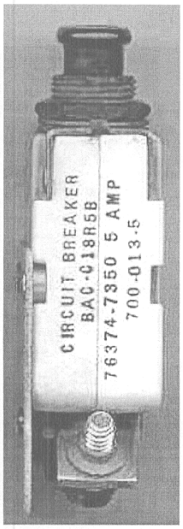
Special Instructions: As the first step in the failure analysis, the OEM will repeat test 59 after the breaker has been cycled off/on five times with no power applied. A low voltage contact resistance measurement will be obtained before the first and after

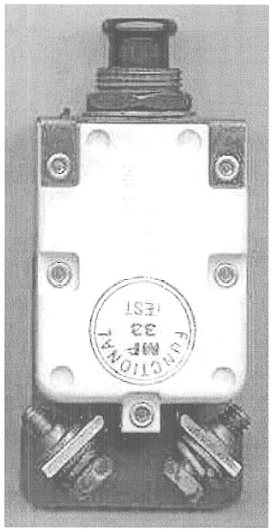
each of the five-off/on cycles. After the cycling process is complete, test 59 will be repeated. Regardless of the outcome of this test, a failure analysis will be performed to determine the cause of the first failure or both failures as applicable. The failure analysis will be conducted by the circuit breaker OEM. The OEM will follow approved, company standard operating procedures (SOP) to conduct the analysis. When the SOP is inadequate for the complete determination of the failure or degradation causal factors, it shall be supplemented with additional procedures necessary to do so. For example, such procedures might include chemical analysis, optical microscopy, electron microscopy, and others.

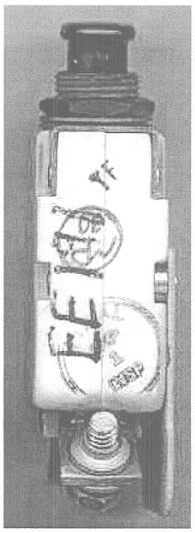
Block 17: **End of Test**

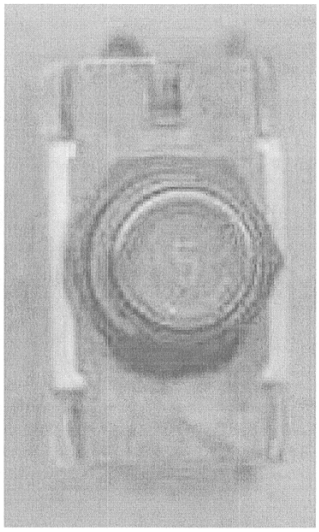
MIL-C-5809 Test Number: NA

Special Instructions: Safely store the CB in a suitable container that will protect the CB from physical or chemical damage. Insure that the breaker is properly labeled. Store the CB in its end of test state. Do not close or open the CB switch, or manipulate the CB in any way. If the circuit breaker has been disassembled, collect and properly store all remaining parts.









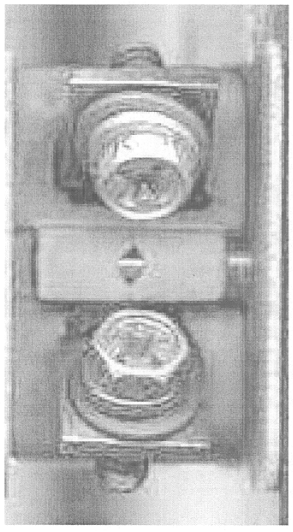


Figure 1.
Exterior of circuit breaker "EE191".

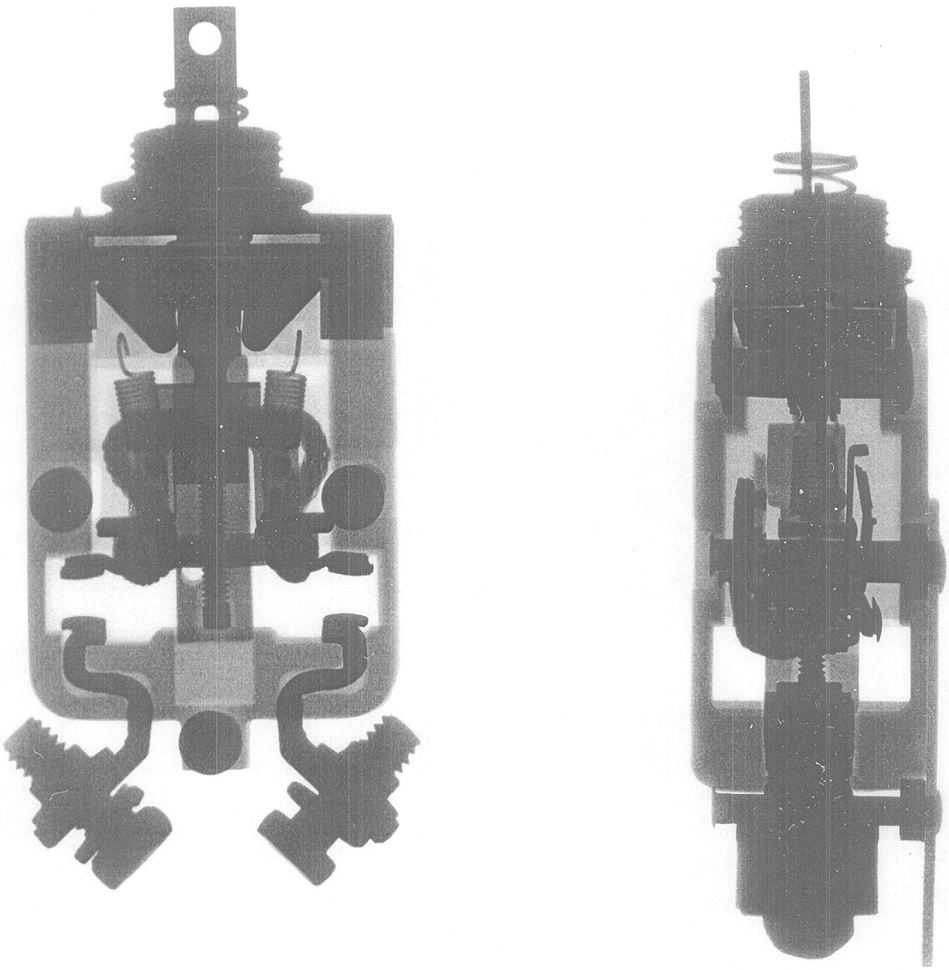


Figure 2.
Radiograph of breaker "EE191" in the open (unlatched) position as received.

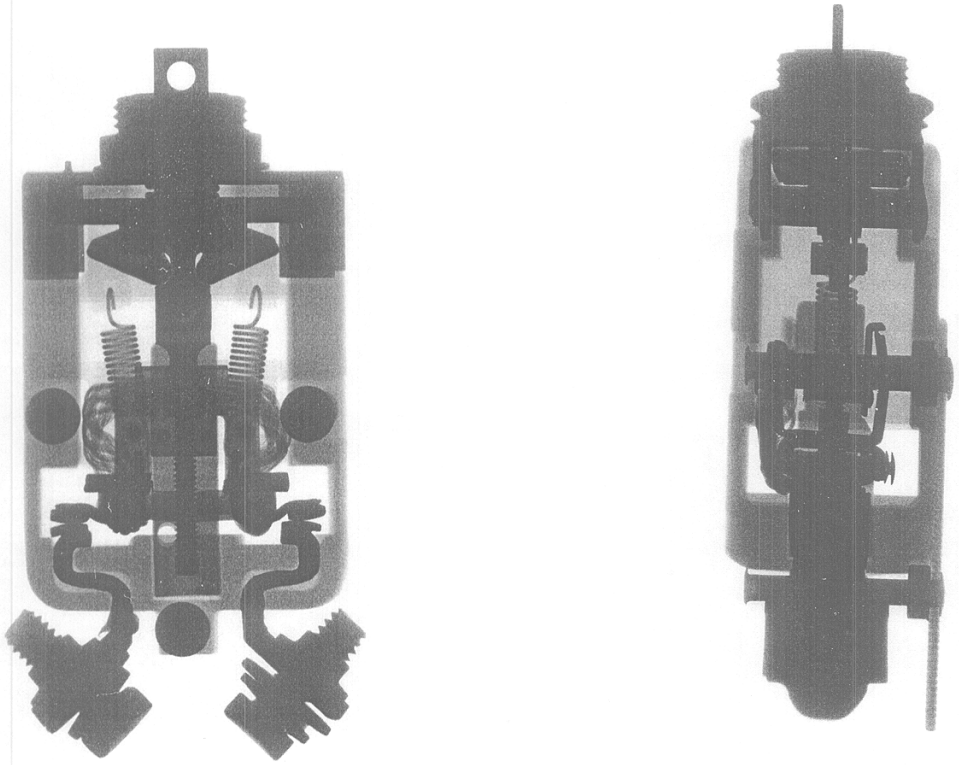


Figure 3.
Radiograph of breaker "EE191" in the closed (latched) position.

APPENDIX G—FAA AIRWORTHINESS ASSURANCE NONDESTRUCTIVE INSPECTION VALIDATION CENTER TEST PROCEDURE FOR CIRCUIT BREAKER FROM AGED AIRCRAFT

TEST PLAN

DRAFT

Aging Aircraft Circuit Breakers

Test Plan Revision: Revision 1, March 14, 2000

Approved: _____ _____
Date

_____ _____
Date

_____ _____
Date

_____ _____
Date

09/06/2001

Contents

1.0 Purpose 3

2.0 Description of parts for testing 3

3.0 Incoming and pretest inspection 4

4.0 Electrical testing 4

4.1 Leakage resistance testing 5

4.2 Pass/fail electrical testing 5

4.3 Testing of failed units 5

5.0 Reporting 6

1.0 Purpose

This document specifies preliminary characterization testing that is to be performed on circuit breakers removed from aged aircraft. The testing objectives are to determine the condition of the breakers with respect to the manufacturers' original specifications, and identify the need for further research.

2.0 Description of parts to be furnished for testing

A total of 48 circuit breakers will be provided for testing. The breakers will be procured in 4 groups of 12 each. Each group shall consist of circuit breakers of the same rating and manufacturer. Together the four groups will represent three current ratings and if possible, at least 3 different manufacturers. The two groups with the same current rating will represent two different manufacturers. Refer to the table below for clarification.

Group	Rating (Illustration only)	Quantity	Manufacturer
1	5A	12	X
2	15A	12	Y
3	15A	12	Not Y
4	35A	12	Z

All circuit breakers will be removed from in-service or retired transport aircraft with over twenty years of operational service. Retired aircraft will have been out of service for no longer than 3 months at the time of removal. Each breaker will be delivered to Sandia National Laboratories with the following information: aircraft type, aircraft number, years and flight hours of a/c, circuit name and number, circuit breaker manufacturer name, circuit breaker setting (off, on, or known tripped) at time of removal from the aircraft. To the extent possible, breakers in each group will be selected from circuits representing a variety of load characteristics (lighting, motors/pumps, avionics, etc.). It is anticipated that all breakers will be of the panel-mount push-pull type, with terminals that utilize ring lug connections attached by screws.

Circuit breakers will be manipulated as little as possible during removal and shipping. Circuit breakers will be removed from the aircraft in the condition found (off, on, or tripped) and will not be exercised at any time prior to testing in the laboratory. At least 8 breakers in each group will be removed in the 'On' position.

3.0 Incoming and pretest inspection

Unpacking of the parts from the shipping container will be done carefully, and the parts will be handled in such a way that there is no change in the on-off condition of the breakers as received.

Parts will be visually inspected, and their condition as received will be documented. Documentation furnished with the breakers will be checked for the information described in Section 2..0. If the breakers are furnished still attached to panels, with wiring, the condition of the wiring and panels will be examined and documented. Any observed mechanical defects in the panels or wiring will be noted. Panel assemblies will be photographed with a digital camera.

Breakers will be removed from the panels, exercising care that breakers in the off position (pulled) are not inadvertently closed. The breakers will be labeled or marked as they are removed from the panels (or unpacked, if not attached to panels) to identify each breaker with the information supplied. The breakers will be visually inspected and the condition of each breaker documented. Any breaker having visual damage or other anomaly will be photographed. Condition of the terminal screws will be noted for each breaker (looseness, corrosion, thread or other damage). If the wiring is attached, any anomalies in the terminal lugs will be noted (poor crimp, sharp bends, corrosion, other). If the breakers are visually dirty or contaminated, they will not be cleaned until insulation resistance measurements are made as described below.

At least one breaker from each group will be radiographed. If there are open and closed breakers (as delivered) from each manufacturer, a sample of each will be radiographed. The radiographs will be inspected for mechanical anomalies.

4.0 Electrical Testing

4.1 Leakage resistance testing

Prior to beginning the test for proper operation, and before cleaning visibly dirty units, insulation resistance will be tested for each breaker by applying 500 V DC potential for one minute, using a suitable tester designed for the purpose, and noting the resistance, or noting current and calculating resistance. The measurement will be made between each terminal and the case mounting bushing for the closed breakers, and additionally between terminals for those breakers received in the open position. Breakers that display less than 10 megohms resistance terminal-to-case will be cleaned by wiping with dry cloth or paper wipes, taking care not to remove markings, and retested. Breakers that measure less than 1 megohm in any configuration will be removed from testing and disassembled for examination.

4.2 Pass/fail electrical testing

The breakers will be connected to automatic testers, open breakers closed, and electrical tests performed as follows, using an applied voltage of 2.5 V DC or less measured at the breaker terminals. The power supplies will have a current capability of at least 150% of the rating of the breaker. All data will be recorded digitally. All measured parameters will be scanned by the testers each 1 second, and the data recorded as specified below.

Test 1. Apply a current through the breaker of 100 mA for 5 minutes, and record the current and voltage drop across the terminals each 10 seconds. Calculate and record the time, current, voltage, and voltage/current ratio (resistance). If the resistance at the end of 5 minutes exceeds 10 ohms, terminate the test and document the failure. Electrically disconnect the breaker from the tester, and measure the resistance with an ohmmeter with leads attached in a manner that minimizes connection resistance, documenting the results. Reconnect the breaker to the tester, reapply 100 mA current, and cycle the breaker manually ten times, with the tester recording voltage, current, and resistance as above. Manual breaker cycling will be done using a gauge that measures force needed to actuate the breaker plunger. If the resistance measured after the mechanical cycling still exceeds 10 ohms, terminate the test and remove the breaker from the fixture, otherwise continue with Test 2.

Test 2. Ramp the applied current over a period of 1 minute from zero to 100% of the rating of the breaker. Hold this current for 1 hour, recording the time, current and voltage across the terminals each 5 minutes, or if there is a change of 2% or more in current or voltage. If the breaker opens during this test, terminate the test and remove the breaker from the fixture. If the rated current cannot be achieved with the 2.5 V power supply limit,.terminate the test and remove the breaker.

Test 3. If the breaker holds 100% rated current for 1 hour, continue the testing, ramping the current up by 2% of the breaker rating each 5 minutes to 138% of current rating. Hold at 138% rating for an additional 55 minutes. Time, current and voltage across the terminals will be recorded each 5 minutes, or if there is a change of 2% or more in current or voltage. If the breaker does not open during this time, terminate the test, and remove the breaker from the fixture.

4.3 Testing of failed units

1. Breakers that fail Test 1 will be disassembled and the interior mechanism and contacts examined and documented. The interior components and contacts will be photographed at the highest available magnification and resolution. Contacts and contact assemblies will be tested with an ohmmeter to attempt to locate the high resistance. Contact assemblies will be sent to a chemical testing laboratory for analysis of surface corrosion.

2. Any breaker that fails Test 2 will be disassembled and visually examined for mechanical damage or anomaly, particularly to the bimetallic contact strip. Results of the physical examination will be documented. Digital photographs will be taken of the parts

3. Breakers that fail Test 3 will be opened manually using a spring scale to measure the opening force required. The manual open and close cycle will be repeated ten times, recording the force needed for opening. The results will be compared with manufacturers specifications if available, and with measurements of a breaker of the same type, manufacturer, and current rating that passed Test 3. If the opening force is high compared with a properly functioning breaker, and remains high, the breaker will be disassembled and examined for mechanical failure or contamination. If the breaker has a manual opening force comparable to the properly operating breaker, the breaker will be returned to the electrical test fixture, and the electrical tests repeated. If the breaker then fails any of Tests 1, 2, or 3, testing will be terminated and the breaker disassembled for examination. If the breaker passes all tests, the breaker will then be disassembled and examined for contamination, particularly around the plunger. Disassembled breakers and parts will be photographed.

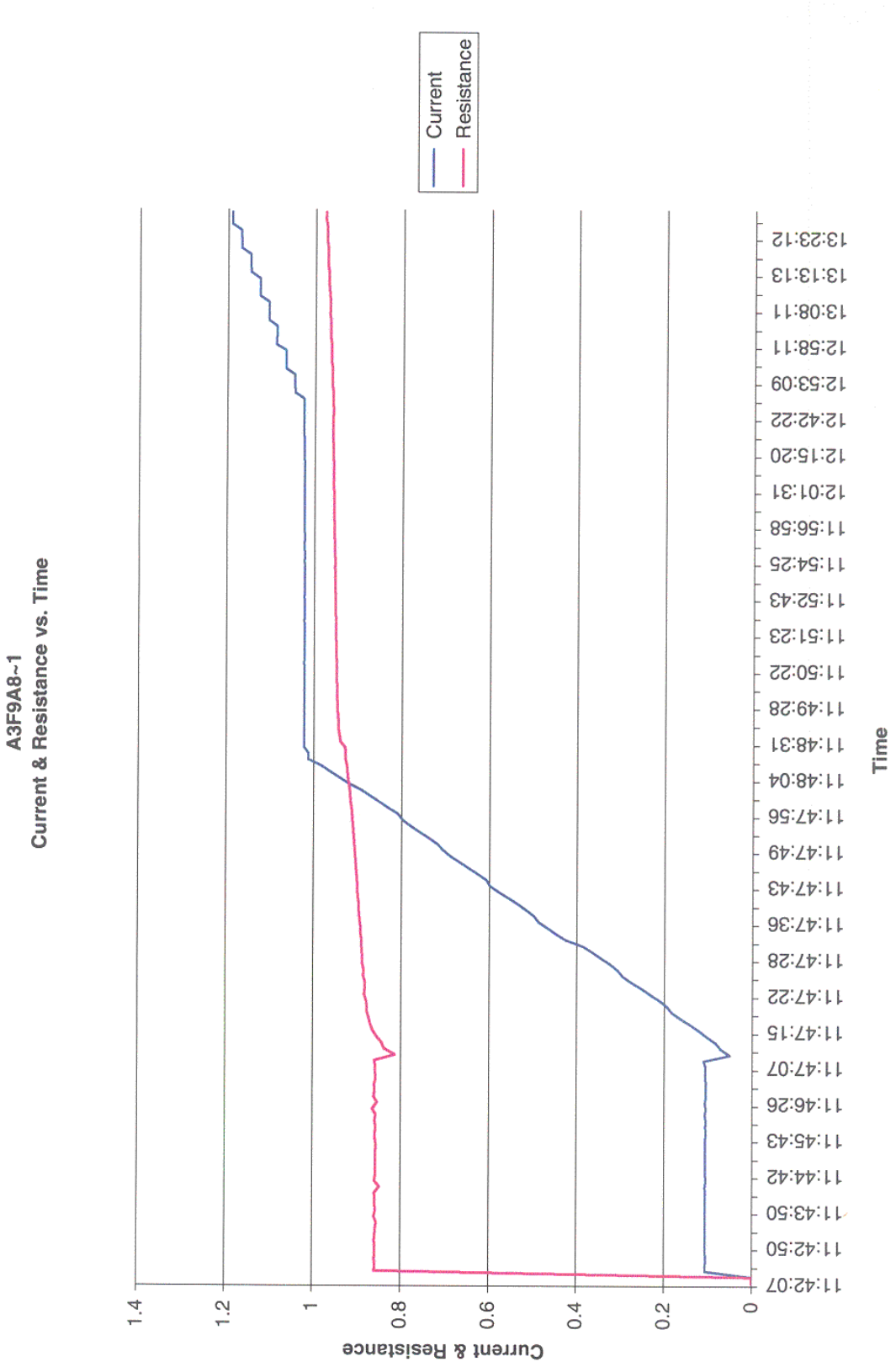
All disassembled breakers will be packaged separately in containers for possible later examination.

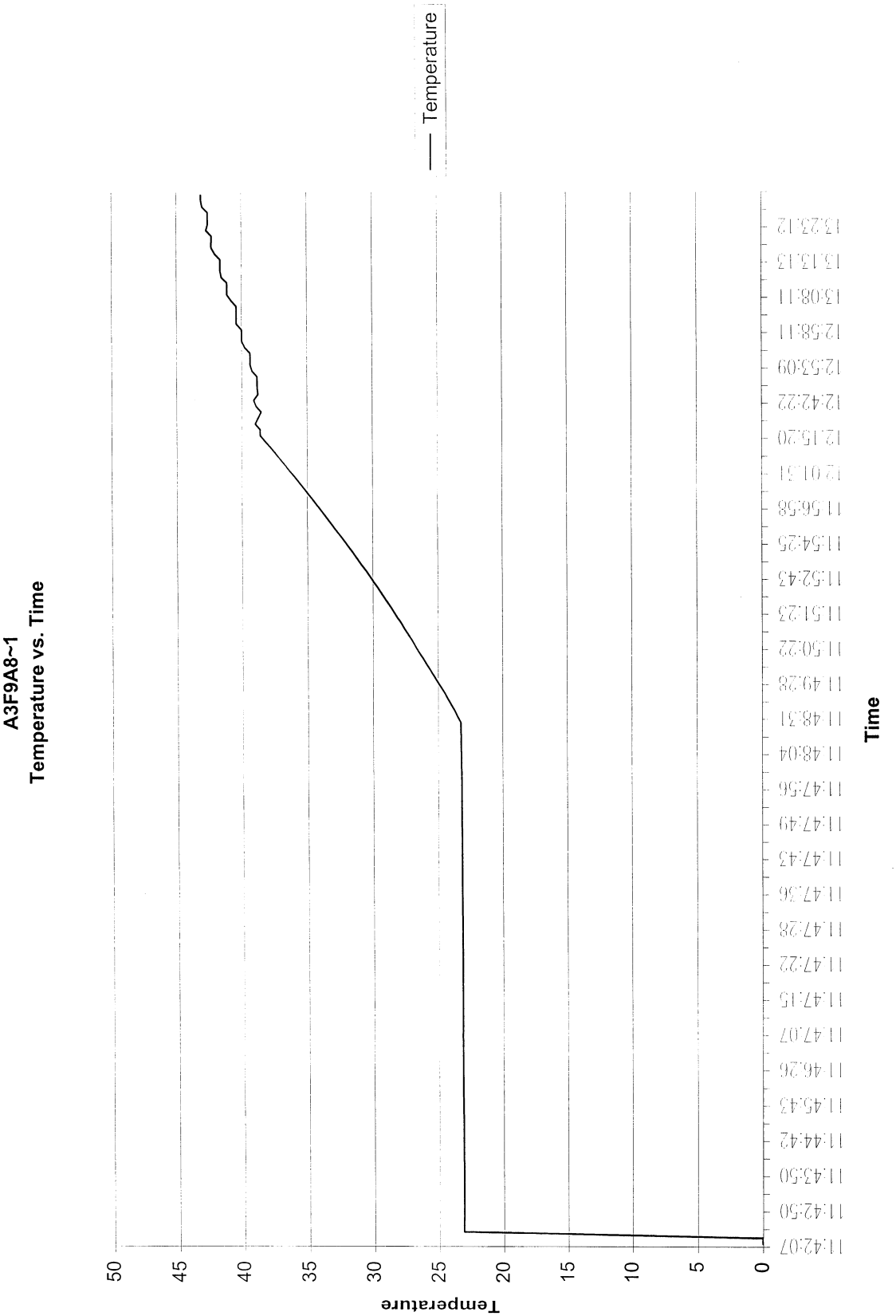
5.0 Reporting

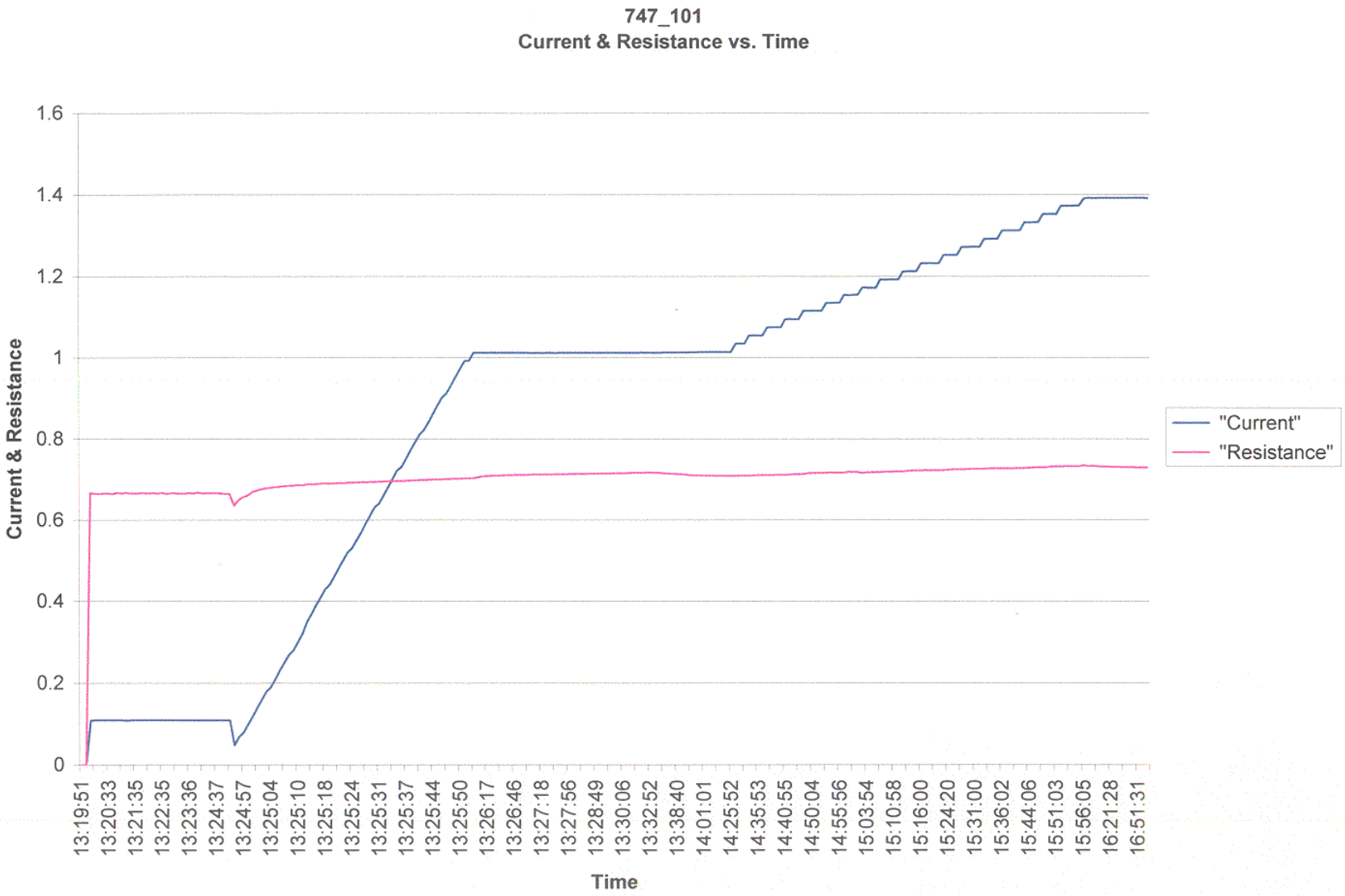
A report will be written describing the testing and results. Complete digital test data from the automatic testers will be supplied if desired in Excel spreadsheet format. Copies of logs of manually recorded test data (visual condition, manual resistance measurements) can be supplied on request. All digital photographs will be supplied electronically in JPEG format. Unless otherwise requested, digital information will be supplied on CDROM.

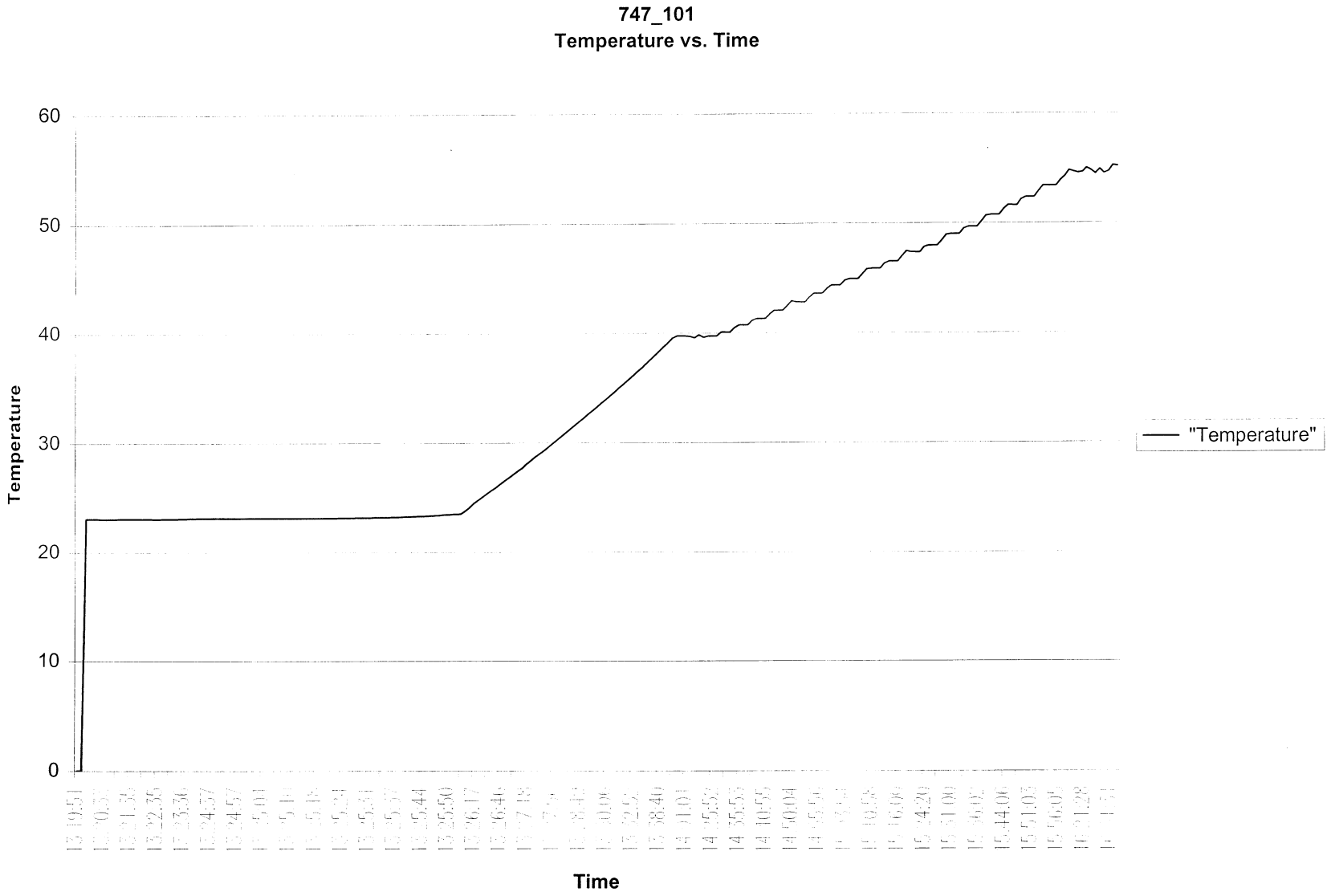
APPENDIX H—FAA AIRWORTHINESS ASSURANCE NONDESTRUCTIVE INSPECTION VALIDATION CENTER TEST RESULTS ON CIRCUIT BREAKERS REMOVED FROM AGED AIRCRAFT

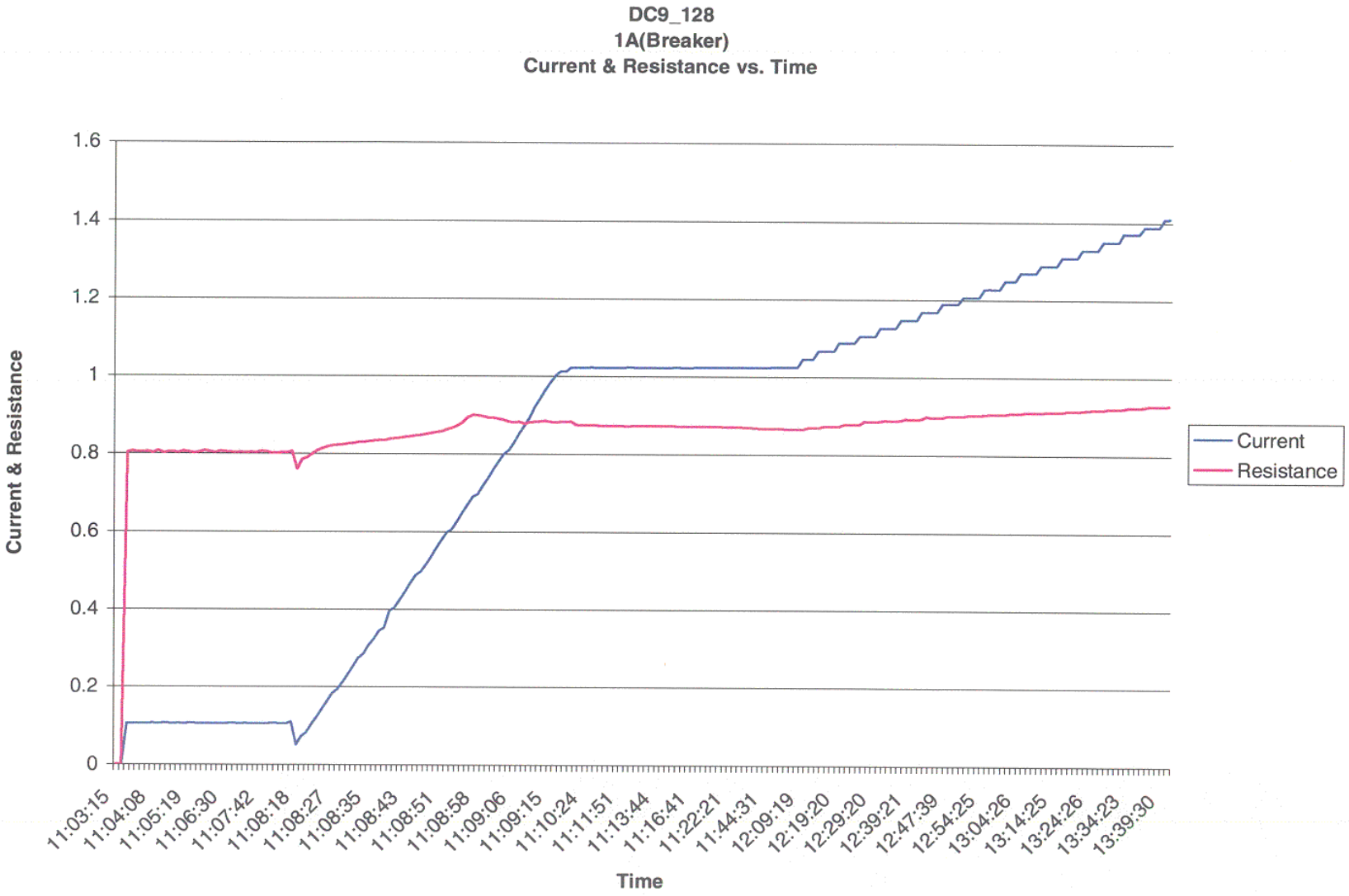
H.1 CURRENT, RESISTANCE, AND TEMPERATURE RISE EXAMPLES.

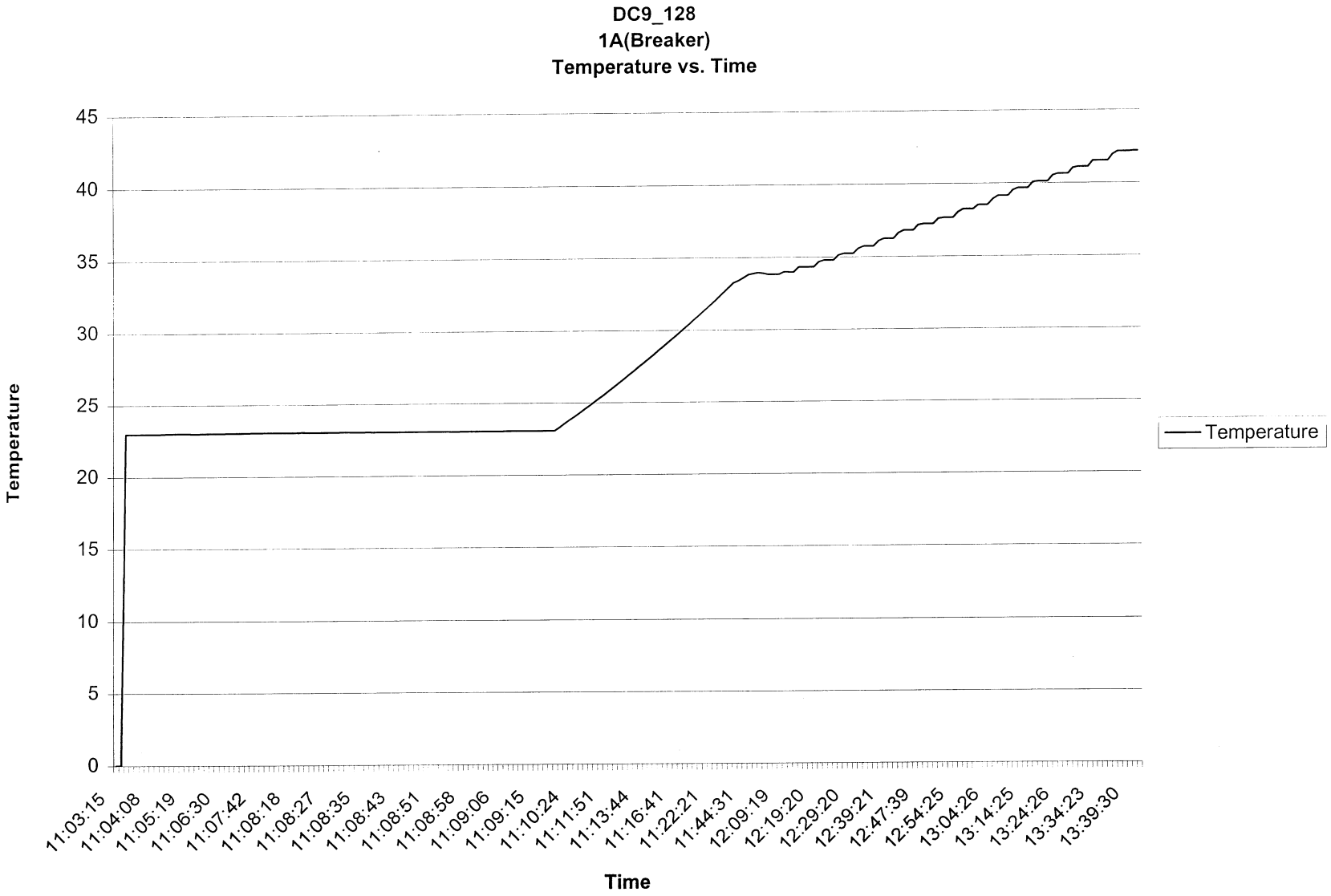



A3F9A8~1
Temperature vs. Time
Temperature
Temperature
Time
0
5
10
15
20
25
30
35
40
45
50
11:42:07
11:42:50
11:43:50
11:44:42
11:45:43
11:46:26
11:47:07
11:47:15
11:47:22
11:47:28
11:47:36
11:47:43
11:47:49
11:47:56
11:48:04
11:48:31
11:49:28
11:50:22
11:51:23
11:52:43
11:54:25
11:56:58
12:01:51
12:15:20
12:42:22
12:53:09
12:58:11
13:08:11
13:13:13
13:23:12


747_101
Current & Resistance vs. Time
Current & Resistance
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
13:19:51
13:20:33
13:21:35
13:22:35
13:23:36
13:24:37
13:24:57
13:25:04
13:25:10
13:25:18
13:25:24
13:25:31
13:25:37
13:25:44
13:25:50
13:26:17
13:26:46
13:27:18
13:27:56
13:28:49
13:30:06
13:32:52
13:38:40
14:01:01
14:25:52
14:35:53
14:40:55
14:50:04
14:55:56
15:03:54
15:10:58
15:16:00
15:24:20
15:31:00
15:36:02
15:44:06
15:51:03
15:56:05
16:21:28
16:51:31
Time
"Current"
"Resistance"


747_101
Temperature vs. Time
60
50
40
30
20
10
0
Temperature
Time
"Temperature"


DC9_128
1A(Breaker)
Current & Resistance vs. Time
Current & Resistance
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
11:03:15
11:04:08
11:05:19
11:06:30
11:07:42
11:08:18
11:08:27
11:08:35
11:08:43
11:08:51
11:08:58
11:09:06
11:09:15
11:10:24
11:11:51
11:13:44
11:16:41
11:22:21
11:44:31
12:09:19
12:19:20
12:29:20
12:39:21
12:47:39
12:54:25
13:04:26
13:14:25
13:24:26
13:34:23
13:39:30
Time
Current
Resistance


DC9_128
1A(Breaker)
Temperature vs. Time
Temperature
45
40
35
30
25
20
15
10
5
0
11:03:15
11:04:08
11:05:19
11:06:30
11:07:42
11:08:18
11:08:27
11:08:35
11:08:43
11:08:51
11:08:58
11:09:06
11:09:15
11:10:24
11:11:51
11:13:44
11:16:41
11:22:21
11:44:31
12:09:19
12:19:20
12:29:20
12:39:21
12:47:39
12:54:25
13:04:26
13:14:25
13:24:26
13:34:23
13:39:30
Time
Temperature

FAA SUMMARY OF SANDIA LABORATORY DATA

ID	mfr	rating	test minutes	trip	current %	volts	current	resistance	bkr temp	amb temp	notes
747-100	CBMA	1	216.21	n	138%	1.003	1.41	0.7134	48.59	23.07	
747-101	CBMA	1	216.21	n	138%	1.016	1.39	0.7298	55.19	22.70	
747-102	CBMA	1	216.23	n	138%	1.012	1.39	0.7285	47.87	22.70	
747-103	CBMA	2.5	216.18	n	138%	0.407	3.45	0.1178	50.05	22.70	
747-104	CBMA	2.5	117.37	y	122%	0.401	3.08	0.1301	44.32	22.90	
747-105	CBMA	2.5	146.58	y	134%	0.392	3.37	0.1162	44.86	22.00	
747-106	CBMA	5	138.34	y	130%	0.282	6.53	0.0431	47.21	22.90	
747-107	CBMA	5	216.15	n	138%	0.295	6.94	0.0425	49.96	22.70	
747-108	CBMA	5	216.21	n	138%	0.298	6.92	0.0431	55.41	22.80	
747-109	CBMA	5	133.33	y	128%	0.267	6.42	0.0416	48.43	23.00	
747-110	CBMB	7	138.76	y	130%	0.347	9.08	0.0383	58.87	25.15	
747-111	CBMA	7.5	217.05	n	138%	0.236	10.32	0.0229	58.66	23.59	
747-112	CBMA	7.5	218.21	n	138%	-0.244	10.35	0.0235	57.79	22.94	
747-113	CBMA	7.5	134.66	y	128%	0.216	9.59	0.0225	52.02	23.60	
747-114	CBMA	10	157.96	y	138%	0.265	13.78	0.0193	70.19	23.86	very hot
747-115	CBMA	10	217.66	n	138%	0.253	13.76	0.0184	62.39	23.09	
747-101-rt	CBMA	1	216.21	n	138%	0.985	1.39	0.7079	54.73	23.03	
747-102-rt	CBMA	1	123.63	y	124%	0.912	1.25	0.7297	43.36	23.00	
747-103-rt	CBMA	2.5	216.23	n	138%	0.407	3.45	0.1177	49.93	23.04	
747-107-rt	CBMA	5	216.19	n	138%	0.287	6.94	0.0414	48.63	23.04	
747-108-rt	CBMA	5	178.55	y	138%	0.299	6.92	0.0432	55.61	23.13	
747-111-rt	CBMA	7.5	143.68	y	132%	0.247	9.87	0.0250	63.90	25.38	
747-112-rt	CBMA	7.5	217.83	n	138%	0.253	10.35	0.0244	63.81	25.82	
747-115-rt	CBMA	10	217.96	n	138%	0.254	13.77	0.0185	68.63	25.67	very hot
A300-116	CBMC	1	103.07	y	116%	1.163	1.19	0.9770	43.09	22.66	
A300-117	CBMC	1	96.27	y	114%	1.136	1.16	0.9837	42.38	22.79	
A300-118	CBMD	3	138.01	y	130%	0.340	3.92	0.0868	48.27	23.11	
A300-119	CBMD	3	113.52	y	120%	0.606	3.60	0.1681	55.01	23.14	
A300-120	CBMD	3	141.20	y	132%	0.402	4.00	0.1006	55.50	23.11	
A300-121	CBMD	3	132.06	y	128%	0.362	3.86	0.0937	52.96	23.15	
A300-122	CBMD	5	107.88	y	118%	0.345	5.93	0.0581	57.84	22.57	
A300-123	CBMD	5	126.24	y	126%	0.304	6.34	0.0479	55.41	22.59	
A300-124	CBMD	5	131.17	y	128%	0.298	6.43	0.0463	56.78	22.61	
A300-125	CBMD	5	136.80	y	130%	0.297	6.52	0.0456	55.95	22.75	
A300-126	CBMD	10	111.82	y	120%	0.205	11.98	0.0172	54.66	24.50	
A300-127	CBMD	10	15.67	y	100%	0.430	9.95	0.0433	62.51	24.03	early trip, high resistance
DC9-128	CBMA	1	156.39	y	138%	1.309	1.41	0.9284	42.17	22.72	
DC9-129	CBMA	1	136.92	y	130%	1.181	1.31	0.9000	41.24	22.60	
DC9-130	CBMA	1	216.16	n	138%	1.380	1.39	0.9937	45.40	22.42	
DC9-131	CBMA	1	216.16	n	138%	1.401	1.38	1.0116	44.84	22.42	
DC9-132	CBMA	1	146.83	y	134%	1.346	1.35	0.9940	41.49	22.53	
DC9-133	CBMA	2	131.39	y	128%	0.837	2.58	0.3248	51.88	22.59	
DC9-134	CBMC	1	147.82	y	134%	1.243	1.35	0.9233	52.92	22.53	
DC9-135	CBMC	1	216.24	n	138%	1.303	1.39	0.9393	54.38	22.99	
DC9-136	CBMC	2	116.37	y	122%	1.005	2.45	0.4102	55.55	22.54	
DC9-137	CBMB	5	216.20	n	138%	0.292	6.92	0.0422	46.93	22.53	
DC9-138	CBMC	7.5	137.34	y	130%	0.242	9.72	0.0249	55.45	24.07	
DC9-139	CBMC	10	217.23	n	138%	0.208	13.75	0.0151	56.27	23.73	
DC9-140	CBMC	10	217.55	n	138%	0.211	13.79	0.0153	57.03	23.40	
DC9-141	CBMC	10	217.72	n	138%	0.210	13.76	0.0152	50.91	23.42	
DC9-142	CBMC	10	146.35	y	132%	0.236	13.17	0.0180	56.29	23.93	
DC9-143	CBMC	15	217.67	n	138%	0.208	20.64	0.0101	66.14	23.31	

	Total Tested	Total Passed	Total Failed	1.0	2.0	2.5	3.0	5.0	7.0	7.5	10.0	15.0	Aircraft					
													A		B		C	
													Pass	Fail	Pass	Fail	Pass	Fail
CBMA	21	10	11	8	1	3		4		3	2		6	9			4	2
CBMB	2	1	1					1	1				1					1
CBMC	11	6	5	4	1					1	4	1			2		4	5
CBMD	10	10	0				4	4			2				10			
Total	44	27	17	12	2	3	4	9	1	4	8	1	7	9	12	0	8	8
														0.6		0		0.5
			Pass	6	2	2	4	6	1	2	4							
			Fail	6		1		3		2	4	1						

AIRCRAFT HISTORY	747	A300	DC-9
Aircraft Letter	A	B	C
Year of Manufacture	1973	1978	1967
Flight Hours	100000	40000	75000
Flight Cycles	20348	27078	100017
Date Retired	36281	36342	36373
Date CB Panels Removed from Aircraft	36526	36404	36465
Aircraft Wire Type	PolyX	Polyimide	PVC/Gls/ Nylon
Approximate Age When Inspected	Jan-00	Jan-00	Feb-00
Failures/flight hours	0.00009	0	0.000107
Failures/Flight Cycles	0.00044	0	8E-05
Failures/Age	0.33333	0	0.25

APPENDIX I—CIRCUIT BREAKER MANUFACTURER TO PART NUMBER CODES CROSS REFERENCE TO PART NUMBERS

Circuit Breaker Cross Reference Code

Manufacturer	Mfr PN. Code (- Amp Rating)	Mfr part nunber (- Amp rating)	Test Process 1 or 2
Texas Instruments	A -	7274-55-	1&2
	B -	7274-21-	1&2
	C-	2TC6-	2
	D-	6752-304-	2
	E-7.5	7276-13-7.5	2
	E-8	7276-13-8	2
Mechanical Products	G -	700-013-	1
	H -	700-030-	1/2
	I -	700-066-	1/2
	J -	1500-032-	1
	K -	8500-005-	1
	L -	9500-001-	1
	M -	1536-066-	2
	N -	4310-002-	2
	U-	1200-009-	2
Wood Electric	P - 15	505-215-102-	2
	P - 20	505-220-102-	2
	R - 5	492-205-102-	2
	R - 15	492-215-102-	2
	S - 50	450-250-103-	2
Texas Instruments	CBMA	Klixon	Includes Numerous Part Numbers
Mechanical Products	CBMC	Mech Prod	Includes Numerous Part Numbers
Wood Electric	CBMB	Wood Elect.	
Crouzet SA	CBMD	Crouzet	

APPENDIX J—FAA AIRWORTHINESS ASSURANCE NONDESTRUCTIVE INSPECTION VALIDATION CENTER CIRCUIT BREAKER TEST DATA

In the spring of 2000, Sandia National Laboratories performed current overload testing ranging from 100% to 138% on 52 breakers removed from three aircraft: an Airbus A300, a Boeing 747, and a McDonnell Douglas DC-9. The voltage drops and temperature rises were continuously recorded during the test. The test program is described in appendix G. The data from the Sandia testing was provided by the FAA for inclusion in this test report. Comparison of Sandia National Laboratories results with the Process 1 and Process 2 test protocol results were not performed because the test procedures used to perform the same tests were different and the performance requirements of the breakers tested were not known.

Examples of graphical representations of LVCR, temperature rise, and current rise for the breakers are provided in appendix H. The results indicated that the LVCR was relatively constant during the current rise. The results also indicated that the temperature rises followed the current rises. The results are not unexpected, since the breaker contact resistance is designed to be consistent and the breaker is designed to open as a function of temperature rise due to increased current.

A sanitized summary of the Sandia National Laboratories data, which was developed by the FAA, is also provided in appendix H. This summary includes the aircraft histories.

The results are depicted as charts in figures 1 through 7 and are described as follows:

a. Figure J-1 provides the distribution of the manufacturer's circuit breakers tested.

b. Figure J-2 provides the quantity of circuit breakers tested by current rating and manufacturer.

c. Figure J-3 provides the circuit breaker pass/fail totals for each manufacturer. It also graphically depicts the total number of breakers passing versus the total number of breakers failing.

d. Figure J-4 provides the number of pass/fail breakers as a function of current rating.

e. Figure J-5 compares the number of breakers that passed or failed for the three aircraft. Aircraft A is the B747, aircraft B is the A300, and aircraft C is the DC-9.

f. Figure J-6 compares the aircraft flight hours to flight cycles.

g. Figure J-7 compares the circuit breaker failures per flight hours, failures per flight cycle, and failures per service life (years) of the aging aircraft.

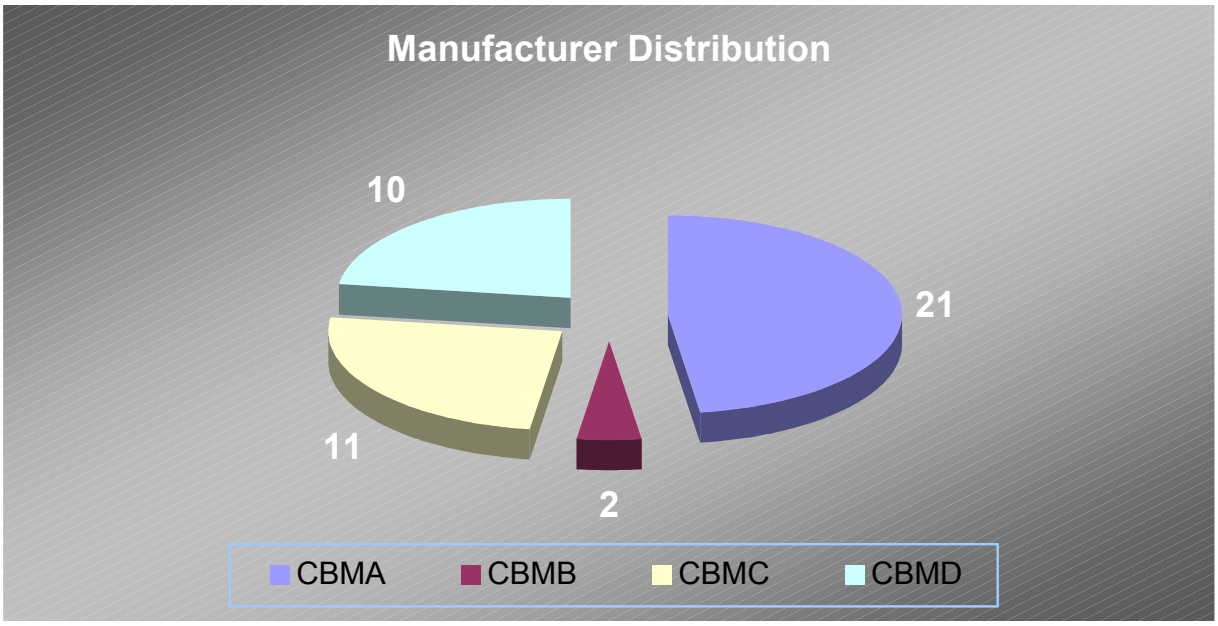


FIGURE J-1. FAA AANC SAMPLE DISTRIBUTION OF MANUFACTURER'S CIRCUIT BREAKERS

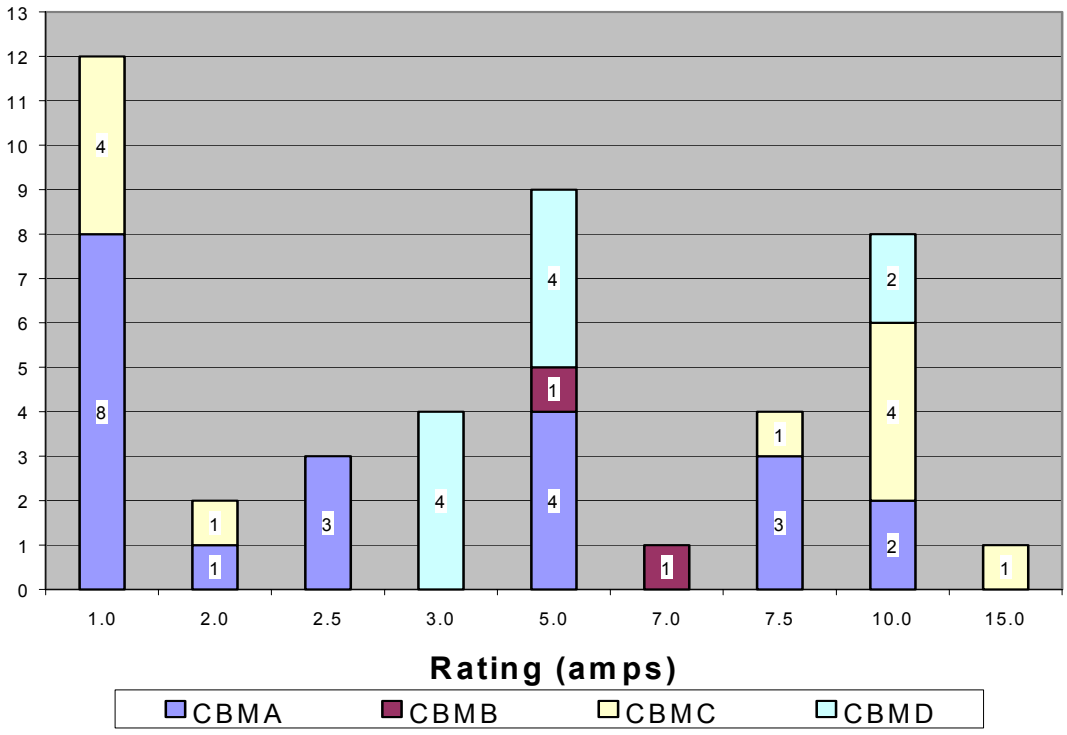


FIGURE J-2. FAA AANC CIRCUIT BREAKER SAMPLING BY AMPERE RATING AND MANUFACTURER

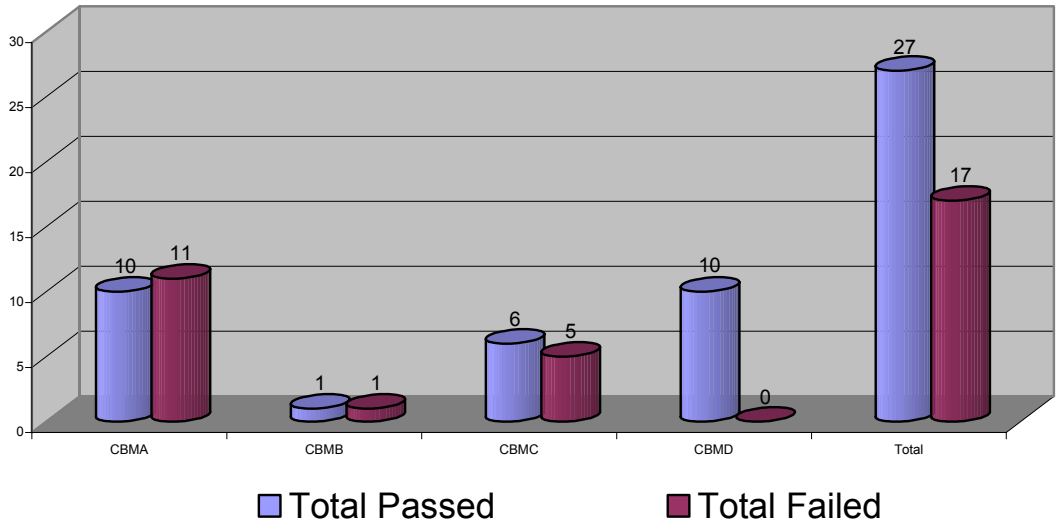


FIGURE J-3. FAA AANC CIRCUIT BREAKER TOTAL PASS/FAIL RESULTS BY MANUFACTURER

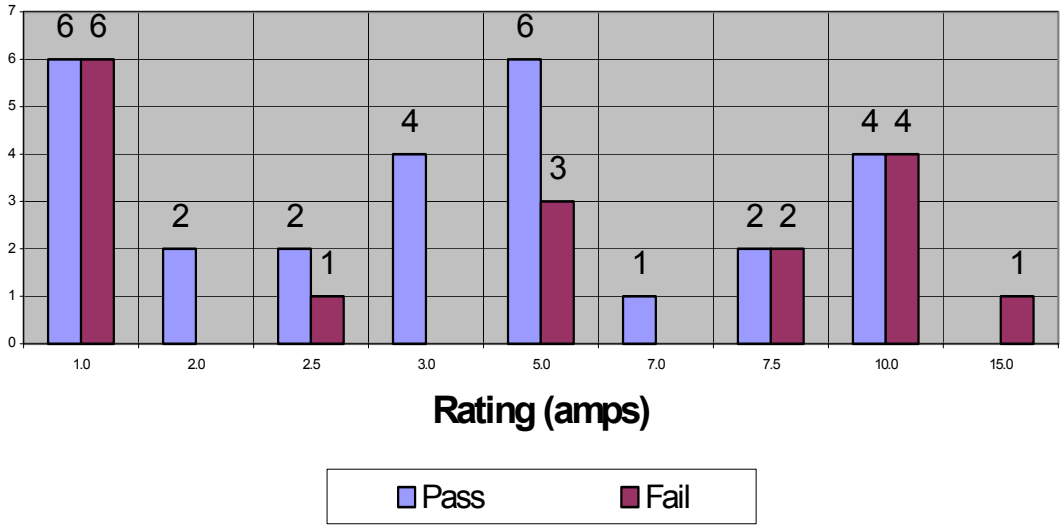


FIGURE J-4. FAA AANC CIRCUIT BREAKER PASS/FAIL RESULTS BY AMPERE RATING

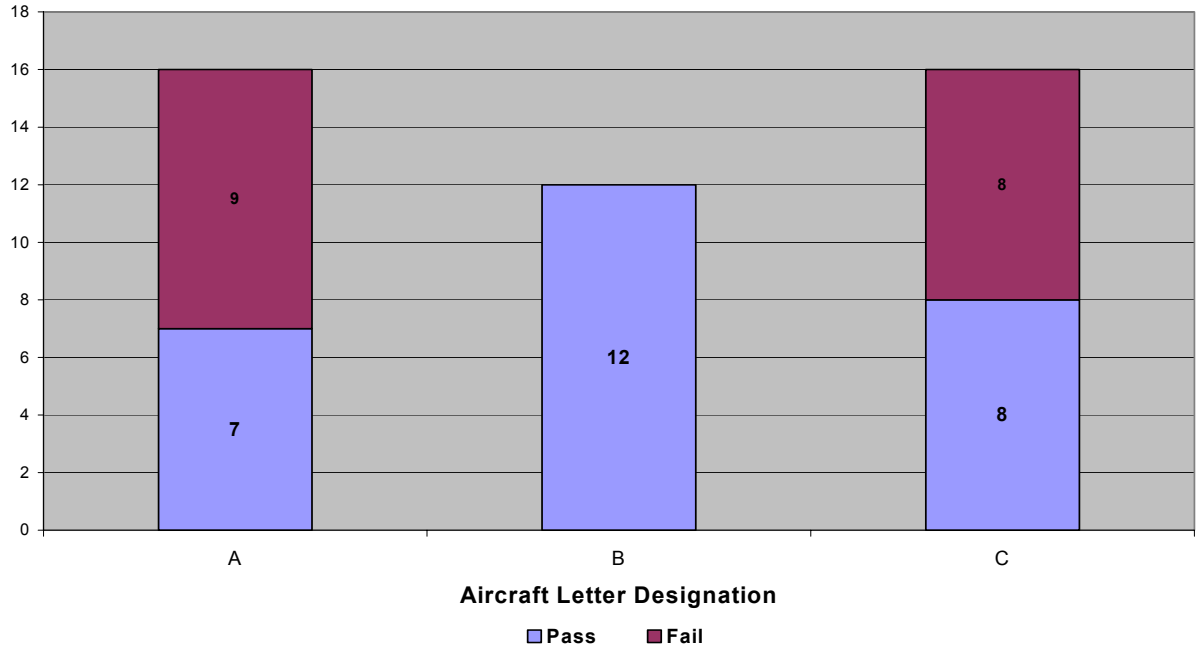


FIGURE J-5. FAA AANC CIRCUIT BREAKER PASS/FAIL BY AIRCRAFT DESIGNATION

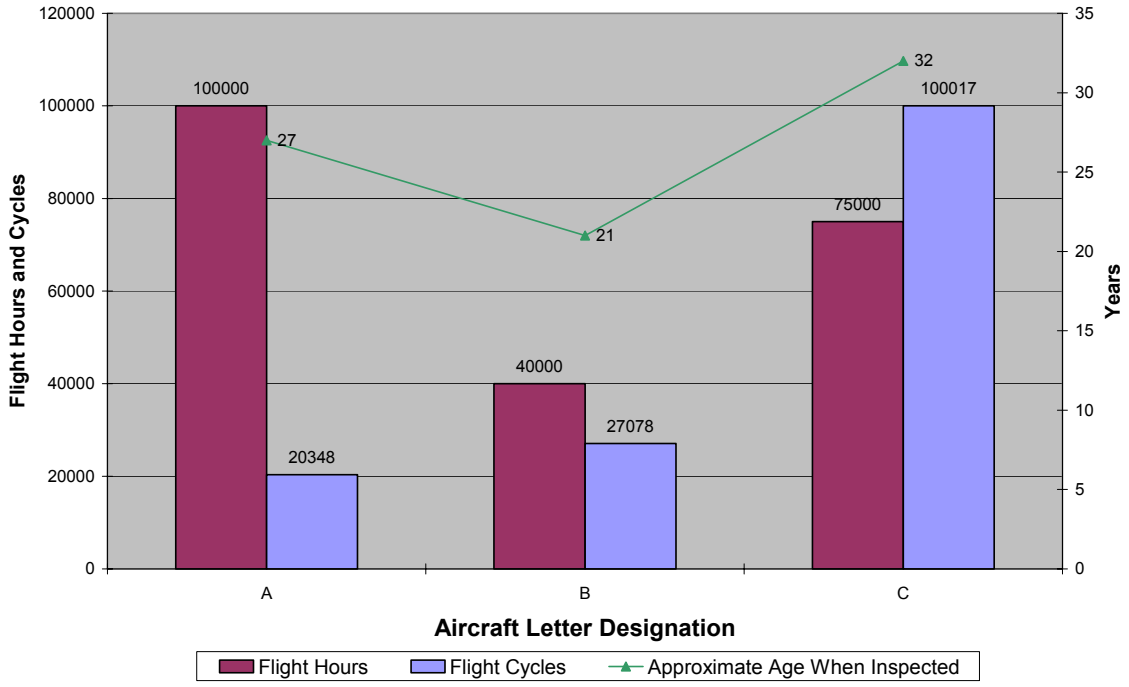


FIGURE J-6. FAA AANC AIRCRAFT FLIGHT HOURS COMPARED TO FLIGHT CYCLES INSPECTIONS

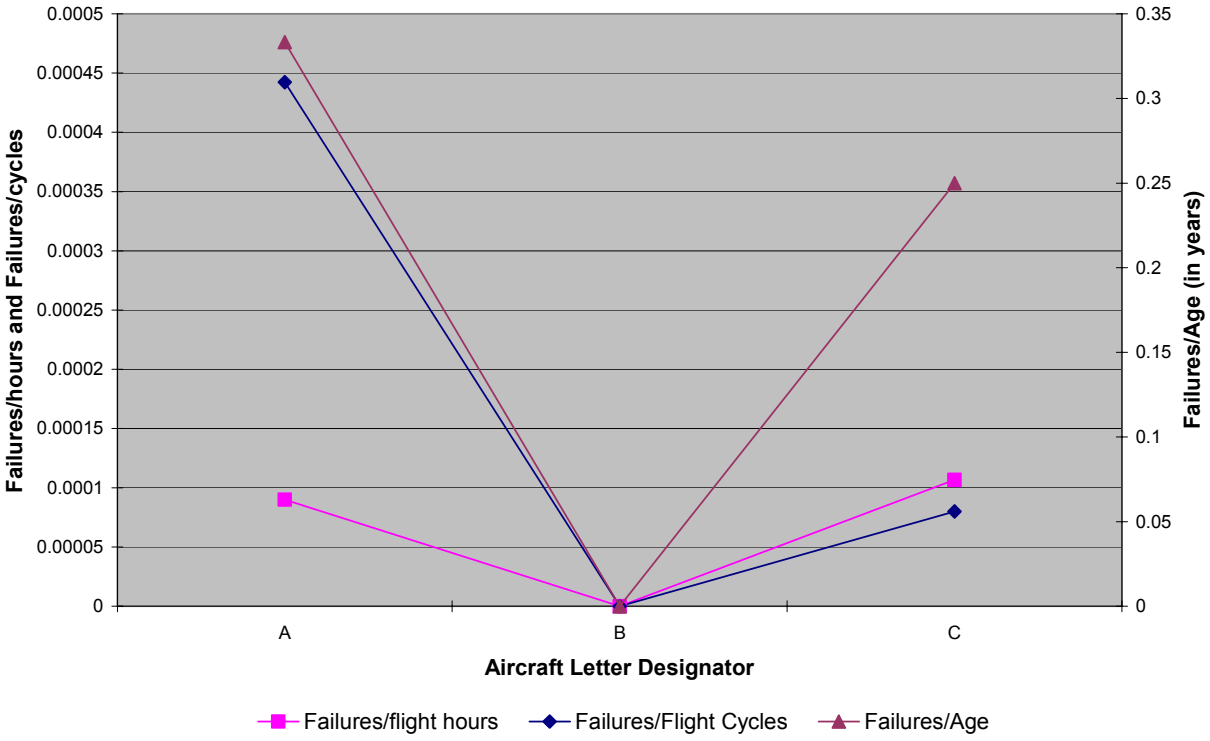


FIGURE J-7. FAA AANC CIRCUIT BREAKER FAILURES PER AIRCRAFT HOURS, CYCLES, AND AGE