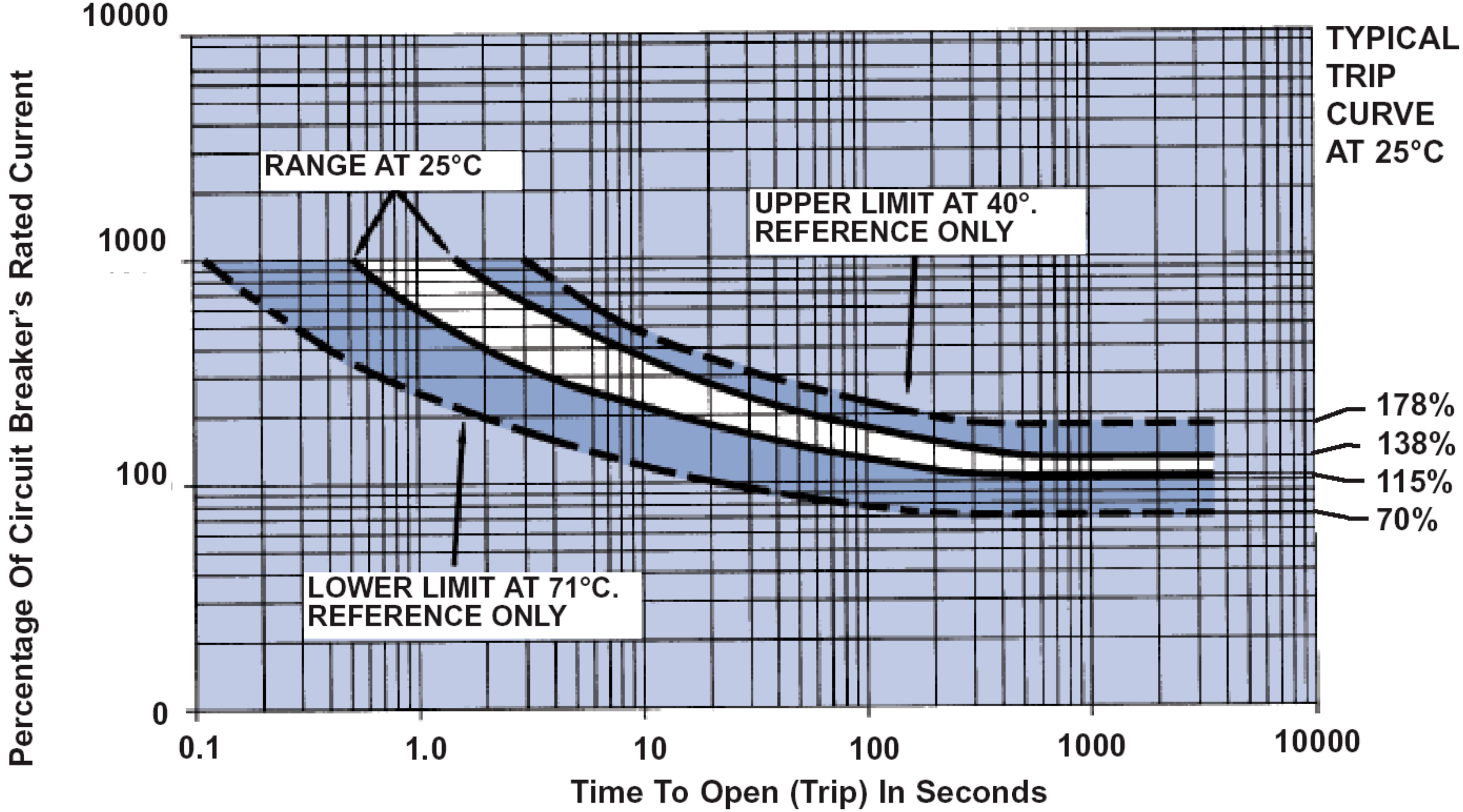
Exemplar CB Trip Characteristics



Exemplar CB Trip Requirements

OVERLOAD CALIBRATION DATA

Specification Table	@ 25°C		@ +71°C		@ -40°C		Test Time Parameters
	MIN	MAX	MIN	MAX	MIN	MAX	
Must Hold	100	—	70	—	110	—	% For 1 Hour
Must Trip	—	125	—	125	—	160	% Within 1 Hour
200% Overload	15	70	—	—	—	—	Seconds
400% Overload	2	12	—	—	—	—	Seconds
600% Overload	1	5	—	—	—	—	Seconds

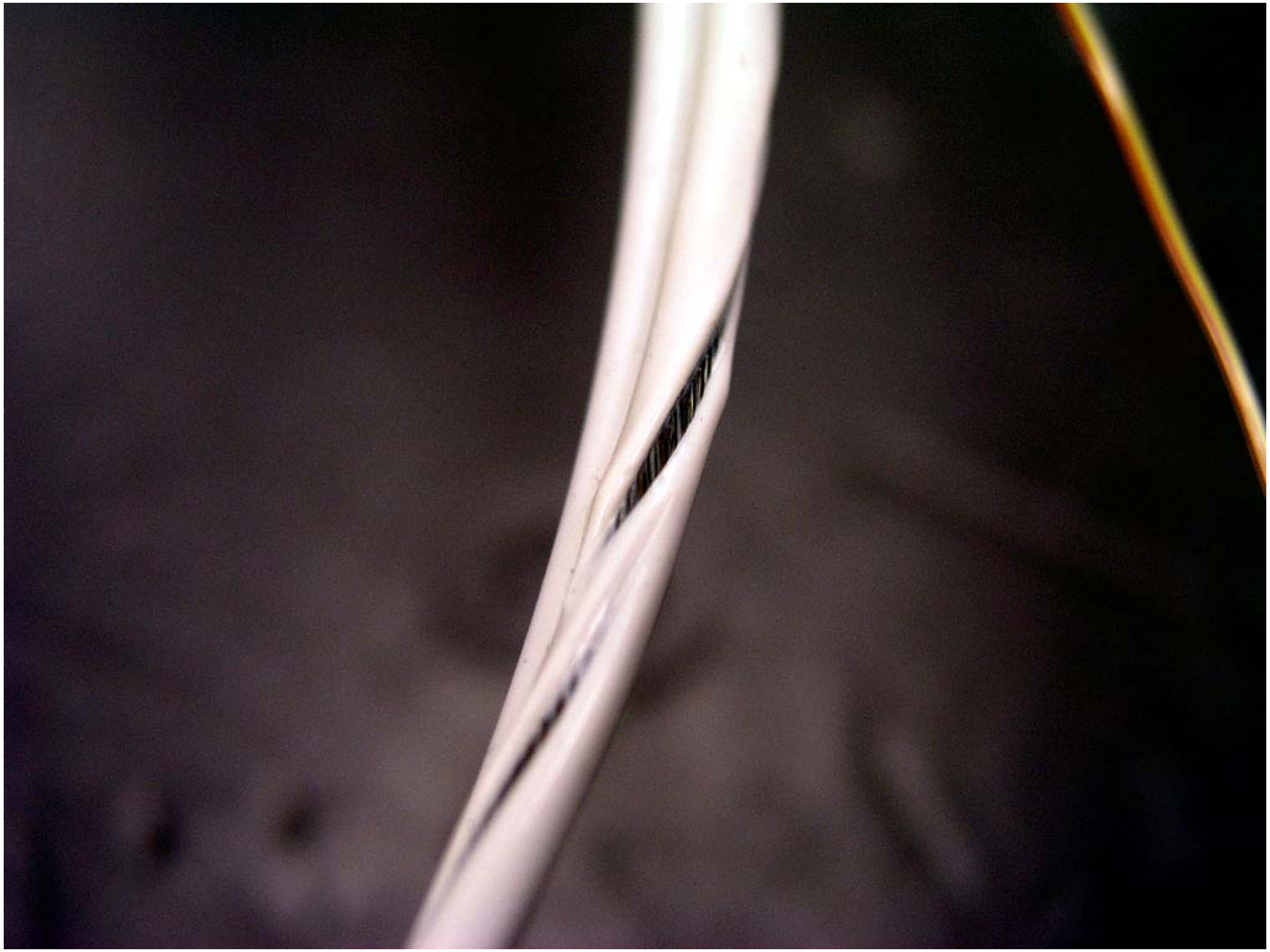
Trip curve available.

Temperature Rise Stabilized at ~ 20 minutes

Temperature under a tye-wrap rose to 260C

Temperature between tye-wraps was 227C

Damage to wire after 40 minutes @ 83A
Under Fiberglas/Silicone Sleeve



Effects of temperature coefficient of copper on temperature rise of 10AWG wire . . .

$$R_t = 0.010\ [1+.0039\ (T_{conductor} - 20)\ ]$$

$$T_{conductor} = R_t I^2 (\theta_{conductor-surface})$$

$$T_{conductor} = \{0.010\ [1+.0039\ (T_{conductor} - 20)\ ]\ \}\ I^2\ (\theta_{conductor-surface})$$

Note that $T_{(conductor)}$ appears on both sides of the equation for $T_{(conductor)}$ with a positive effect. This says that temperature rise on a wire not only goes up with square of current but gets a boost from tempco of copper. A regenerative effect . . .

Realistic Expectations?

Is the 82A test relevant to the question of safety of flight?

The one-hour carry for 160% at -40C is but one of thousands of points that describe operation of the circuit breaker.

For example, suppose we load the system with a 41A, two-hour soft fault. The breaker will NEVER open yet the potential for dumping energy into the fault is the same as for the 82A case.

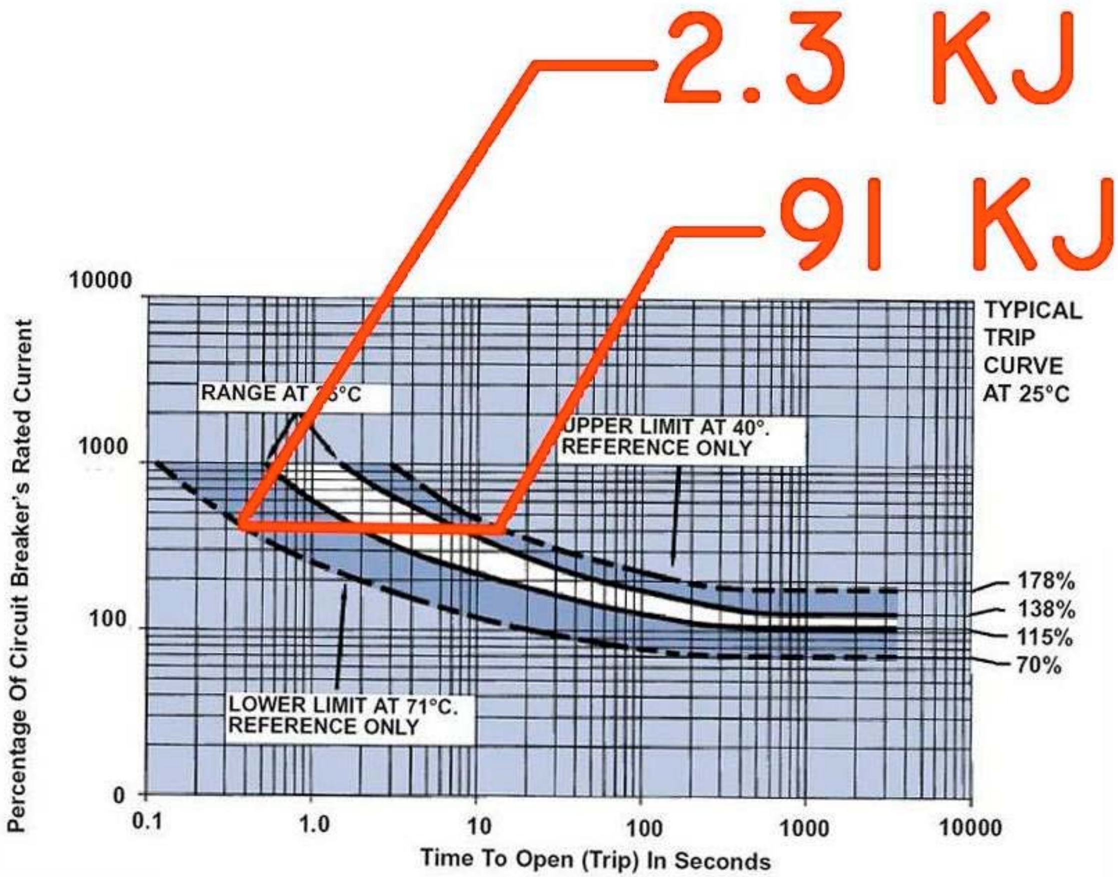
How does one craft a 82A, 2-hour fault?

Hard Fault Definition:

Circuit Protection opens quickly (< 10 seconds). Substantial portion of energy dumped during the event is spread over the resistive components in series with energy source. Total energy dump measured in tens and hundreds of Killojoules.

The World of Hard Faults:

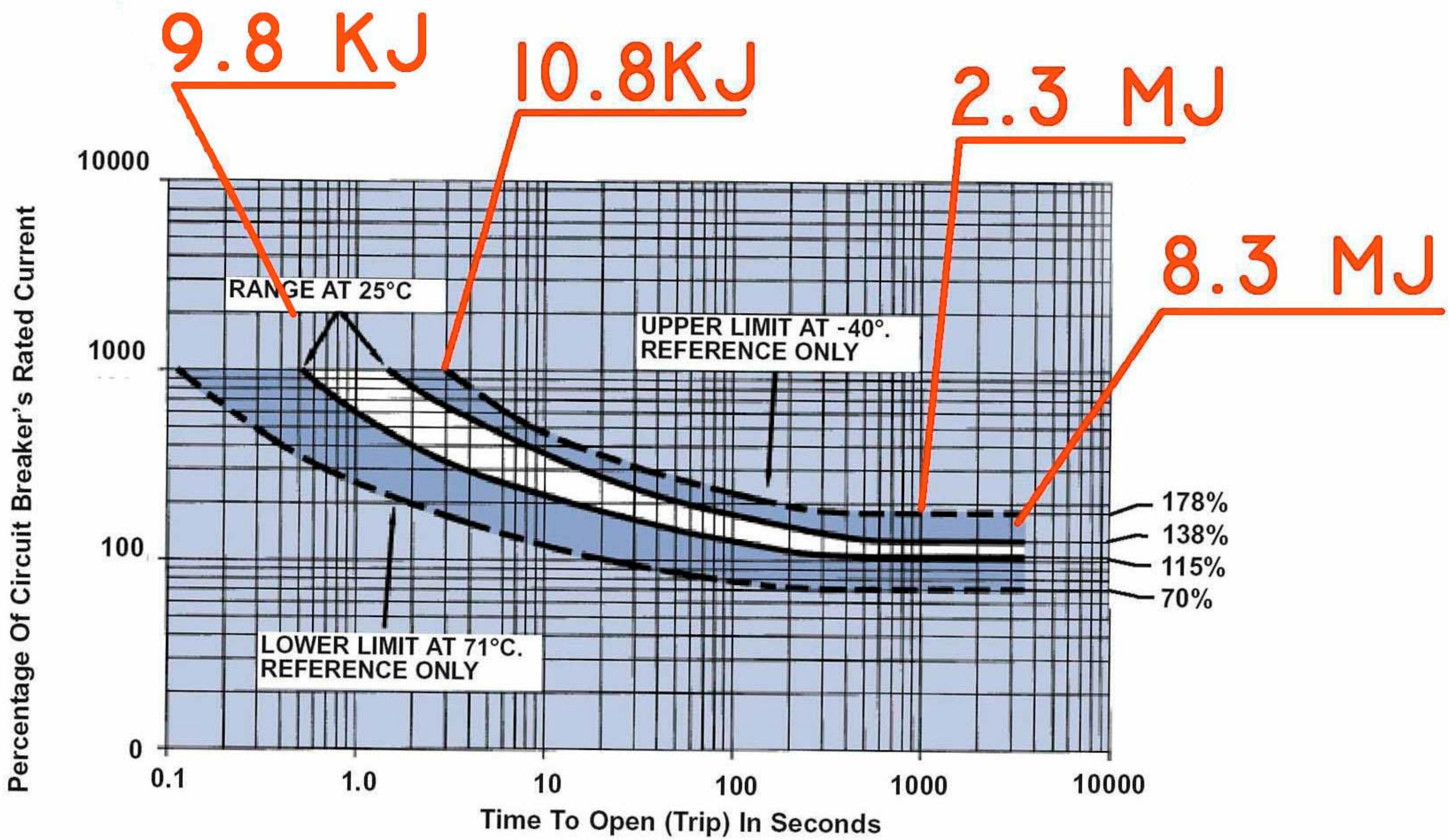
50A CB Trip at 218AFault. Resistance for a “hard” fault is low and the fault dissipates only a small portion of total energy expended. Energy expended is distributed over the various components of system source impedance including the breaker itself and the faulted wire.



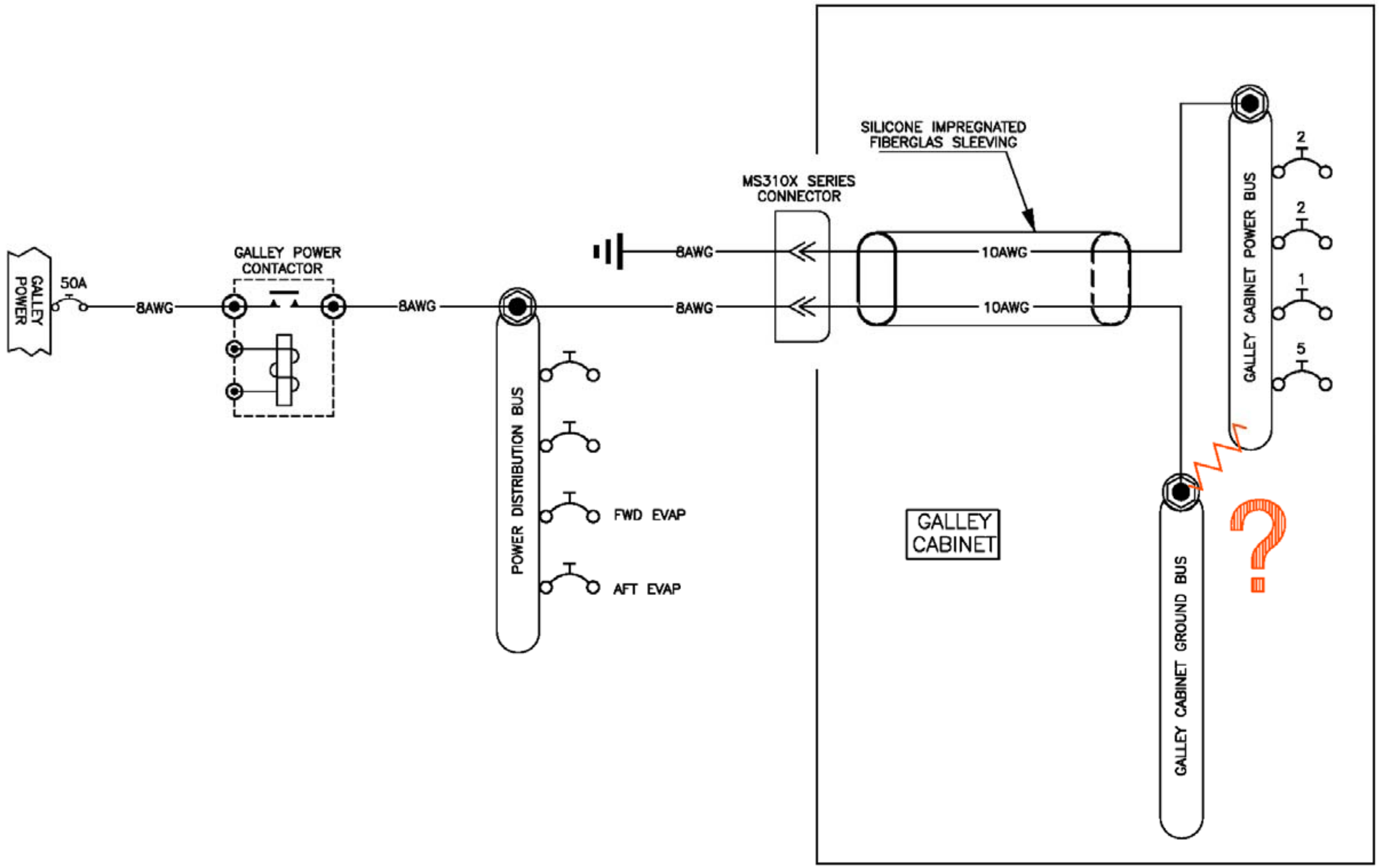
Soft Fault Definition:

Fault condition is protracted in time - minutes to hours. Majority of energy dumped during the event is concentrated at the fault location. Total energy dump is unbounded and measured in Megajoules.

Energy dissipation for various fault conditions . . .



How and where can we hypothesize an enduring 83A fault? What volume would it occupy?



The World of Soft Faults:

In 1999, an E90 was on final to Clovis, NM when elevator cables became “unhooked”. Landing was accomplished with power and pitch-trim. Examination revealed that Copilot’s heated windshield feeder was inappropriately secured during earlier maintenance. Feeder rubbed (and presumably arced) against elevator cable to the point of failure. No smoke noted. No electrical system anomalies noted. 40A breaker did not operate.

This is a good example of substantial energy being dumped into a very small volume over a long period of time and causing damage hazardous to flight.

The World of Soft Faults:

A DC arc welding set runs about 70VDC. Assume 200A setting for welding heavy plate (14,000 watts). Assume 1/4” per second of bead formation or 56,000 Joules per inch of weld.

Consider the 8 MJ test conducted on the 10AWG wire:

This means that energy dumped into our dial-a-fault generator for the 40 minute wire test would have run a 9-foot bead of arc weld in a boilerplate joint!.

The World of Soft Faults:

The World of Soft Faults:

AC43.13-1B . . .

11-48. DETERMINATION OF CIRCUIT BREAKER RATINGS. Circuit protection devices must be sized to supply open circuit capability. A circuit breaker must be rated so that it will open before the current rating of the wire attached to it is exceeded, or before the cumulative rating of all loads connected to it are exceeded, whichever is lowest. A circuit breaker must always open before any component downstream can overheat and generate smoke or fire. Wires must be sized to carry continuous current in excess of the circuit protective device rating, including its time-current characteristics, and to avoid excessive voltage drop. Refer to section 5 for wire rating methods.

Excerpt from Eaton Breaker Catalog . . .

Why Don't Aircraft Circuit Breakers Provide Protection from Arcing Faults?

Aerospace circuit breakers are designed to protect wiring from thermal damage that occurs during an over-current situation. They are able to do this by deploying a bi-metallic element that mimics that thermal effect of current on a wire's insulation.

The reason circuit breakers do not provide protection from arcing events is that they are not designed to. The characteristics of an arcing event include fault currents that are sporadic or sputtering, have values several times the breakers rating, and the arc event is of such a short duration that the circuit breaker has little time to react.

Summary of Simple-ideas surrounding fault characterization:

Hard fault:

- Short duration
- Low total energy
- Easily mitigated by thermal devices (fuses, breakers, current limiters)
- Energy dissipation spread over length of source-to-fault feed path
- Energy density at the fault is low
- Potential for damage is low

Soft fault:

- Protracted duration
- High total energy
- Cannot be detected by thermal protective devices
- Energy dissipation concentrated in small volume
- Energy density at the fault is high
- Potential for damage is high

Summary of simple-ideas surrounding wire protection:

Electrical:

- Place a current sensing device in series with the circuit to be protected.
- Characterize that protection and the wire so that NORMAL continuous loads do not place the wire's insulation at risk when considerations are made for operating environment.
- Thermal breakers only detect and mitigate hard faults. If there is risk of soft fault the use of arc-detection breakers is indicated.

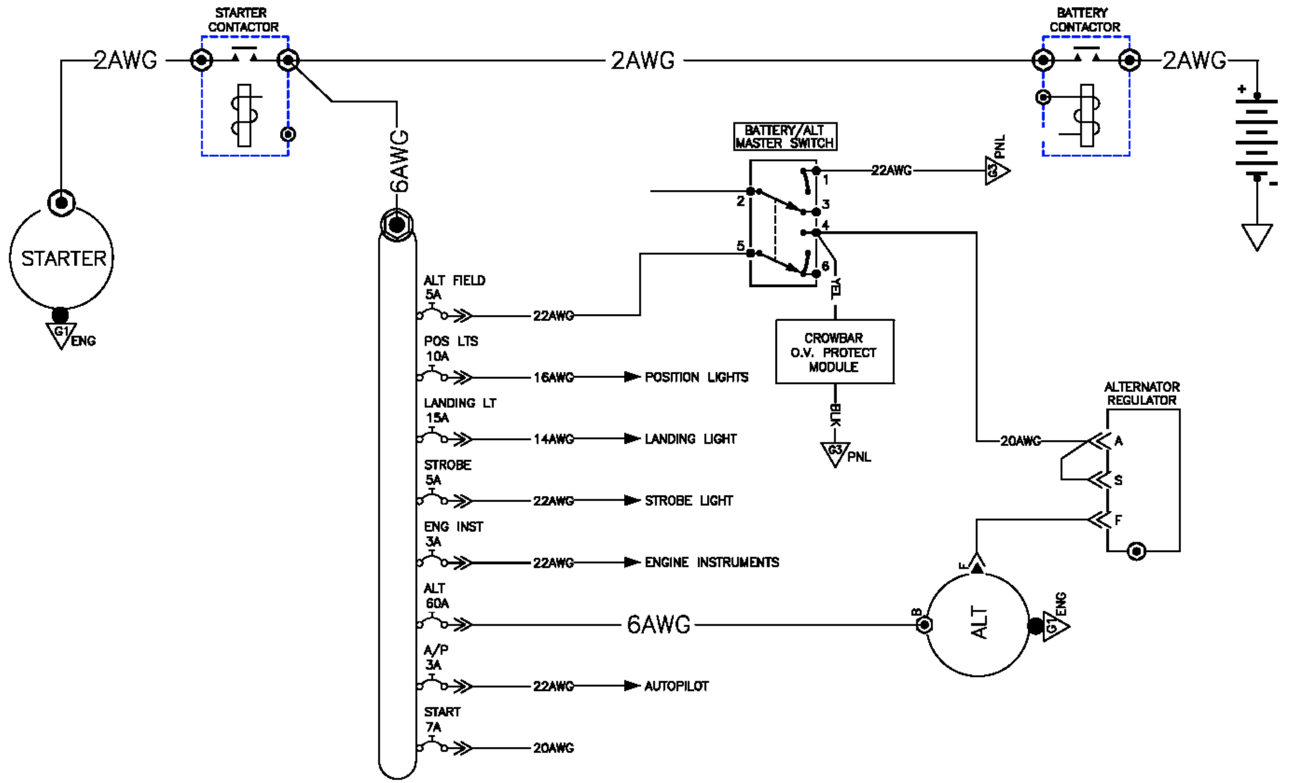
Mechanical:

- Bundle wires, secure to structure to prevent flexing/chafing of bundles.
- Provide clearance from structure and still more clearance from fluid lines and moving parts.
- Avoid exposing wire to fluid hazards (hydraulic, oil, ozone, etc).

Summary of design features for the galley cabinet wiring:

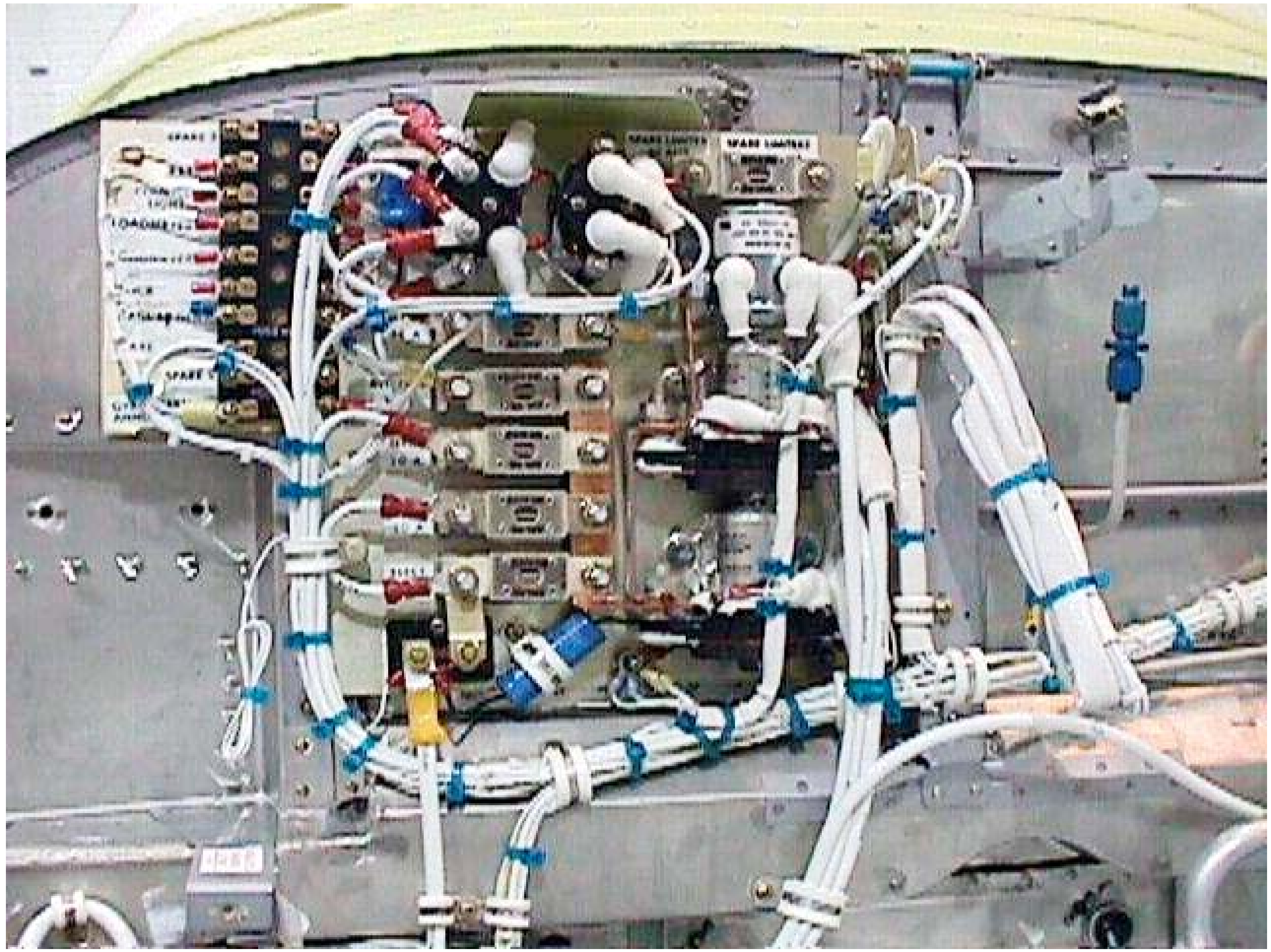
- •Wire bundle carrying the 10AWG wires is well protected in the airplane.
- •Robust insulation (Tefzel) is doubled up with silicone/Fiberglas overlay.
- •No potential for isolated and undetected exposure to moving parts or hazardous fluids.
- •Operating environment is about as benign as it gets . . . The cabinet shares space with passengers.
- •A hard fault to the 10AWG wire would easily open the 50A main feeder breaker.
- •Hard and soft faults of the far end of the 10AWG feeder are mitigated by an array of small (1-10A breakers) on the galley cabinet bus.

There is historical prescient in thousands of SE aircraft with rear mounted batteries where feeder to starter is 2AWG but feeder to bus and alternator is smaller. When mechanical protection per Mil-W-5088 offers confidence for fault free operation, the bus and alternator feeders are downsized in accordance with ***largest anticipated continuous*** load . . .



ANL City on the Bonanza Firewall . . .

Bonanza does use an array of ANL limiters to protect reduced wire-size feeders . . .



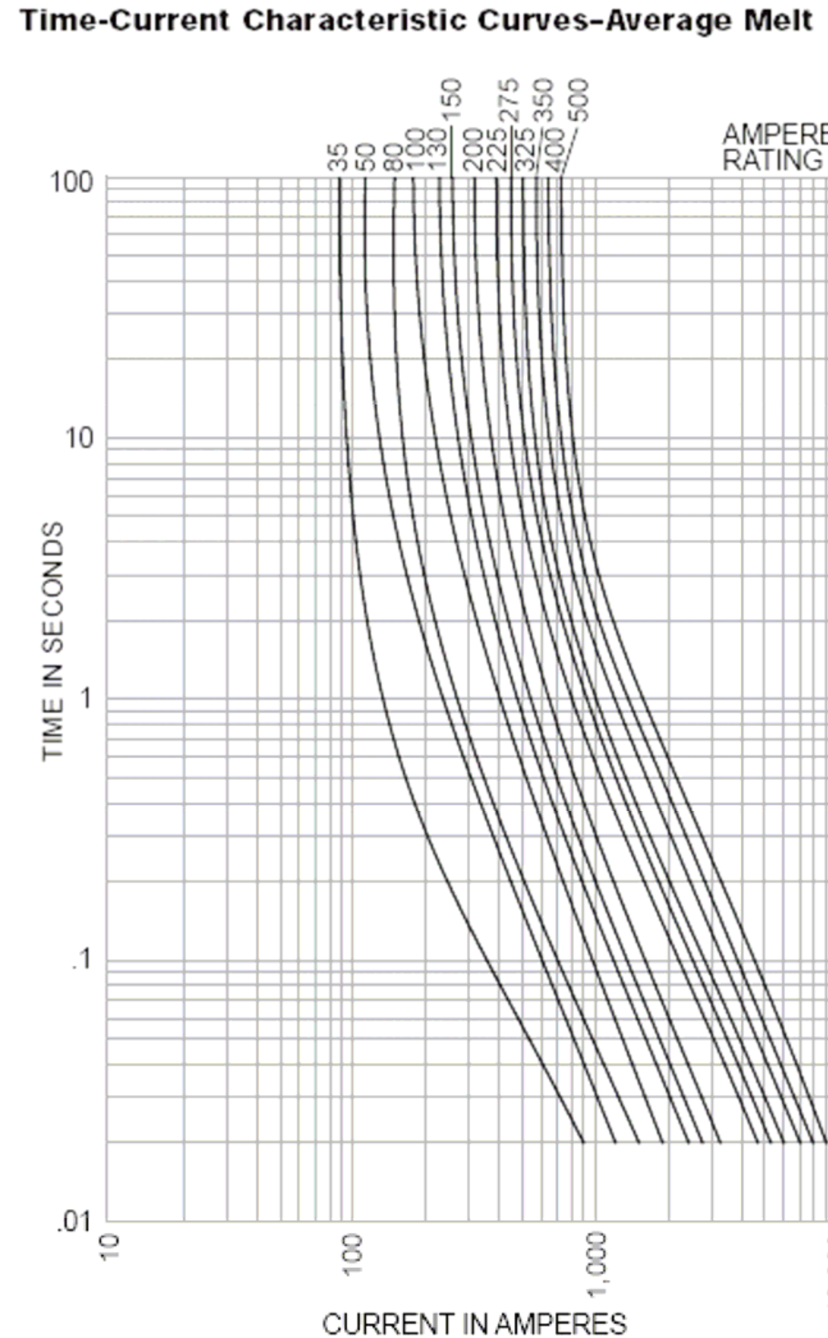
•ANL current limiters are widely used at RAC and throughout aviation for protection of feeders including Bonanzas and Barons.

•Suppose we installed an ANL 35 to "protect" the 10AWG wire in question . . . .

•Note ANL35 carries 70A indefinitely.

•An ANL35 installed in observance of the rule-of-thumb recommendations, offers little improvement in the protection physics for soft faults.

•Like circuit breakers, ANL limiters are decidedly "hard fault" protection only!



Does the 10AWG wire present a safety of flight issue?

Conclusions:

- AC43.13-1B, Paragraph 11-48 is in error. It ignores the nature of soft faults and and cannot be complied with.
- The 83A wire-bundle heating experiment was interesting but not relevant to this study.
- The 10AWG wire in question is adequately protected against soft faults by virtue of the design and installation of the galley cabinet that follows the sprit and intent of Mil-W-5088 combined with . . .
- The 10AWG wire in question is adequately protected against hard faults by virtue of the 50A main feeder breaker and the combination of smaller breakers on the galley cabinet bus.
- The 10AWG wire is more properly considered a bus feeder than a supply line to a single appliance.
- Based on points examined in the foregoing study and cited above, I believe no hazard exists and and "corrective action" would not add value to the airplane.