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Selection of Wires and Circuit Protective Devices for STS Orbiter Vehicle Payload Electrical Circuits

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FOREWORD

This document has been prepared by the JSC Engineering Directorate, Orbiter Electrical Wiring and Installation Subsystem to aid in the electrical design of payloads to be carried aboard the Space Transportation System (STS) Orbiter vehicle. It will guide designers in selecting wire sizes and associated protective devices that are acceptable by JSC for Orbiter-borne payloads. Although the information presented is generally applicable to generic aerospace applications, it is limited in scope and is primarily intended to serve the purpose noted above. Therefore, only the ambient pressures and temperatures are addressed that are normally experienced by an Orbiter-borne payload during ground checkout and while inside the Orbiter payload bay. Part numbers and parameters for various protective devices in the appendix are also Orbiter-specific. If the designers choose to use other than "Orbiter-approved" parts they may easily find corresponding values for their specific device which can be substituted for values listed in the tables and used in their calculations.

Many circuits and installations in a design will have more than one configuration that can fulfill all essential safety and reliability needs. This document does not establish requirements, but establishes guidelines form which deviations can be evaluated. Users will be required to identify for individual evaluation only those circuits that do not meet or that exceed the limits established in this document. The result of following this guide will be the delivery of a payload for flight in the Orbiter that will not conflict with the wiring and circuit protection requirements imposed by the Orbiter Payload Safety Panel. A design that is acceptable, based on these guidelines, must still be evaluated by the JSC Materials Branch for insulation compatibility.

Data used in this document is derived from Eagle Engineering's report, "Wire Size Determination for Aerospace Applications."

CONTENTS

FIGURES

1. INTRODUCTION

Electrical designers can find an array of guides to help them select wire size and circuit protection. Until now, however, none would satisfy the unique design requirements of an Orbiter payload in its particular environment using any one of the many types of wire insulation currently available. This document is an attempt to alleviate that situation somewhat by providing designers with methods for selecting wire size and circuit protection that are appropriate to a particular installation. Remember, however, that this acceptance pertains only to the thermal properties of the wire insulation. Material properties of the insulation must still be evaluated and accepted by the JSC Materials Branch.

Besides failing to be unique for a particular application, most guides fall short of the designers' expectations by providing tables and ratings without explanation, leaving them to accept the information on faith alone. This document is no exception since test data is not included. However, many of the more devious idiosyncrasies of spacecraft wire and circuit protection are explained to give insight into some of the values provided in the tables. Graphs and tables are included that may be used in selecting wire sizes and circuit protection. Also, step-by-step instructions are provided to guide the user in the application of the material. In order to provide additional clarity to the rather complex procedure, two examples are worked out in appendix B to illustrate the processes.

Although each aerospace vehicle is unique in its layout and requirements, this guide is an attempt to present a systematic approach to the process of selecting proper wire size and circuit protection for generic spacecraft. It applies to a broad range of aerospace vehicles, but is primarily structured toward the STS with emphasis on payload design and integration. Coverage, therefore, is limited to two ambient pressures: 14.7 psi and 1 x 10^{-6} TORR; and, in vacuum conditions, tow temperature levels: 70°F and 200°F.

The goal of this guide is to provide a single comprehensive source for the determination of wire size and the selection of circuit protective devices for use on Orbiter payloads, while providing general guidelines for circuit design in generic aerospace vehicles. Graphs were generated to identify acceptable current limits

relative to the temperature rating of a variety of wire insulating materials for a broad range of wire sizes. Although the graphs cover stranded, soft-drawn, nickel-plated copper wire in sizes #1/0 AWG to #26 AWG, the ratings are conservative enough to cover silver-plated or solid conductors.

2. SELECTING CIRCUIT PROTECTIVE DEVICES AND WIRE SIZE

The first step in designing the electrical power circuit for electrical or electronic hardware is the selection of a protective device. The specific type selected will be based on its planned utility and location as described in section 3. Generally, a device is chosen with the smallest rating that will, when derated for the environment, carry the initial inrush current and the maximum sustained current required by the load under any operating condition to which it is exposed.

Because of the many variables involved, selection of an appropriately sized wire is more complex than the selection of a suitable protective device. Wire selection begins by utilizing the process described in section 5 to determine the minimum size wire that can safely be used with the protective device and the environments encountered. This wire size is then used to calculate the worst-case voltage drop to the load. If the voltage drop is acceptable, the wire selected is satisfactory; however, if the voltage drop is excessive, a larger wire must be used that will provide an acceptable voltage drop. Although a larger wire may be dictated by the voltage drop, using larger than the minimum wire does not affect the rest of the circuit. The ultimate goal in selecting a wire size is to conserve weight and volume by using the smallest wire that will meet all required electrical and thermal criteria.

The temperature rating of wire insulation is defined by the manufacturer and is usually the maximum continuous temperature that the insulation may reach and still have the manufacturer's guarantee that no physical or chemical degradation will occur. The current-carrying capacity of a wire is the amount of current the wire can carry in its operating environment without causing the insulation temperature to exceed its rating. Consequently, a properly sized wire must be capable of carrying, for an indefinite period of time, the maximum continuous current of which the associated protective device is capable. The wire must carry this level of current without causing the insulation temperature to exceed the rating of that wire.

The actual level of allowable current in a selected environment is the amount of current required to raise the insulation temperature from that of the wire in a nonconducting state (insulation temperature is equal to ambient) to the maximum rated temperature of the insulation. The difference between the ambient temperature and the wire insulation rating is called the "maximum allowable delta-T (DT)." The temperature difference between the ambient temperature and the wire insulation temperature with

any level of current flow up to and including the maximum current allowable is the "actual DT." The terms "maximum allowable DT" and "actual DT" are used extensively throughout this discussion. The heat generated by current flow in the conductor, the ambient temperature and pressure to which the wire is subjected, and the impact of bundling with other wires all play a role in the ultimate level of current a particular insulated wire can safely carry.

Bundling of wires can affect the maximum current a wire can safely carry and must be taken into consideration because a majority of spacecraft wires are grouped into bundles. A multitude of interrelated factors are involved; however, bundling can either enhance or degrade the current-carrying capability of a wire compared with its capability when routed singly. Bundle size, number of loaded wires, magnitude of current in each wire, duty cycles, location of wire in the bundle, and other parameters all play a part in determining the precise level of current a wire may carry. For practical purposes, however, users of this document, except in rare cases, can ignore bundling. Derating of components, conservatism of design, and the implausibility of a large percentage of wires in a single bundle carrying maximum loads simultaneously all combine to minimize the need for bundle derating. Bundles in which a majority of the wires are heavily loaded simultaneously are unique and should be evaluated individually. Figure 6, MIL-W-5088 (K), Bundle Derating Curves, has been included in this document to aid in the evaluation, but is not used in the following discussions.

Testing by Rockwell International (1976) and NASA (1968-1989) has revealed a noteworthy aspect of the DT rise due to current flow in various sizes of Kapton (H-film) and Teflon (TFE) insulated wires. Both testing and analysis indicate that at an ambient pressure of 14.7 psi a specific amount of current will always cause a fixed amount of temperature rise (actual DT) in the insulation regardless of the ambient temperature. This characteristic, however, does not remain true at altitude. To achieve a given actual DT in vacuum conditions, a wire will carry approximately 20 percent more current at an ambient temperature of 200°F than the same wire in an ambient temperature of 72^{O}F.

3. CIRCUIT PROTECTIVE DEVICES

There are currently four types of protective devices approved for use on the STS Orbiter: fuses, circuit breakers, Remote Power Controllers (RPC), and hybrid drivers. Each device has specific characteristics that warrant its use in a particular circuit or location, although the hybrid driver is a switching device and is not normally used for protection.

FUSE

Fuses are generally used in areas where quick response time is required, where a reset capability is not necessary because the circuit is noncritical, or where sufficient redundancies exist to make reset unnecessary. Because no reset provisions are required, fuses are sometimes located in remote areas of the vehicle where there is no crew access. Therefore, after a fuse opens for any reason, there is no way to salvage the downstream circuit.

When operating at sea level conditions, the current-carrying capability of a fuse (table 1) is controlled by manufacturing tolerances allowed by specification. A fuse is required to continuously carry the level of current listed in the "Min. Blow" column without opening, but may be capable of continuously carrying the current listed under "Max. Blow." Both fuses and wires, therefore, must be sized accordingly. (Note: A complete explanation of column headings in table 1 is given on page A-4.)

Operation in space causes derating to become an additional factor to be considered. When used in the Orbiter, small, subminiature, and cartridge fuses with ratings up to 30 amperes are derated 50 percent from the manufacturer's nominal rating. This derating is necessary because the fuse is a thermal device and derives its sea level rating at standard conditions. At sea level the movement of heated air which surrounds the fuse cools it somewhat, through convection. However, since there is no air circulation at zero-g or in a vacuum, the fuse heats faster and opens at a lower current level. In a design that uses fuses to operate at zero-g or in a vacuum, these fuses cannot reliably carry currents higher than the derated levels listed in table 1 as "Max. Appl. Load (50 percent)." It must be noted, however, that the fuse may be operated in a temperature-controlled environment or in the path of circulating cabin air. In such cases it may be capable of delivering its full sea level "Max. Blow" capability even in orbit.

Orbiter fuses larger than 30 amperes depend very little on convection for cooling, but upon thermal conduction through their mounting device; consequently, they require no derating.

CIRCUIT BREAKER

Circuit breakers are used in circuits that require reset capability and are in locations accessible to the crew. The circuit breaker, like the fuse, is a thermal device and must be derated for operation in space. Because it is much less dependent on convection cooling than small fuses, however, the derating factor is much smaller. As with fuses, when referring to table 1, a circuit breaker operating in space should not be required to continuously carry greater than the "Max. Appl. Load," but may be capable of continuously carrying the "Max. Blow" current at sea level.

REMOTE POWER CONTROLLER (RPC)

The RPC is a solid-state device that acts as a single-pole dc relay. It may be switched remotely by a 28 vdc signal to the "On" or "Off" state. It contains current-sensing and current-limiting circuits that continuously monitor the conducted current. In the event of an overload, it limits the current to a predetermined maximum for a specified time, then interrupts the flow of current to the load and signals the event. The RPC can be remotely reset and, if the overload is no longer present, it will again operate normally. Since the RPC is not a thermally operated device, no derating is necessary.

HYBRID DRIVER

The hybrid driver is a small, solid-state, remotely controlled dc switching device that contains a fusible link in the power circuit. It can be switched remotely to the "On" or "Off" state, but cannot be reset after a malfunction causes the link to open. For that reason, hybrid drivers are not used for circuit protection but usually have a fuse or other device in series to protect the circuit and the driver. The fusible link serves only as a backup.

4. FIGURES AND TABLES

FIGURE 1 - SELECTION OF WIRE SIZE AND CIRCUIT PROTECTIVE DEVICE (page 15)

This chart provides a step-by-step outline of the procedures involved in selecting a circuit protective device and appropriate wire size for most applications. Blanks are provided for entering information needed to complete the process. In addition, the steps indicated on the table correspond to those described in section 5 that may be referred to if additional information is required.

FIGURE 2 - CURRENT-CARRYING CAPACITY OF INSULATED WIRE (page 16)

This step-by-step outline depicts the procedures involved in determining the current-carrying capacity of copper wire. It covers wires ranging in size from #1/0 AWG to #26 AWG operating in various ambient conditions. The wire may be insulated with material of the designer's choosing.

FIGURE 3 - SINGLE WIRE IN FREE AIR (page 17)

This graph illustrates the relationship of wire insulation temperature rise as a function of conducted current for a single wire at sea level conditions.

FIGURE 4 - SINGLE WIRE IN A VACUUM AT 200 DEGREES F AMBIENT (page 18)

This graph illustrates the relationship of wire insulation temperature rise as a function of conducted current for a single wire at 1×10^{-6} TORR, 200°F ambient.

FIGURE 5 - SINGLE WIRE IN A VACUUM AT 72 DEGREES F AMBIENT (page 19)

This graph illustrates the relationship of wire insulation temperature rise as a function of conducted current for a single wire at 1×10^{-6} TORR, 72°F ambient.

FIGURE 6 - MIL-W-5088 (K) BUNDLE DERATING CURVES (page 20)

This figure has been included for the user's consideration when evaluating unique applications where a majority of wires in a bundle are heavily loaded (as discussed in section 2 of this document). The figure has been extracted from the Department of Defense document entitled Wiring, Aerospace Vehicles, dated December 24, 1984. Further information regarding this figure may be obtained by referring to the complete specification.

FIGURE 7 - PROTECTION OF PARALLEL POWER WIRES (page 21)

This figure has been included since it is often necessary that several wires be paralleled to provide sufficient current to a load. It illustrates protection requirements for power wires in parallel.

TABLE 1 - ORBITER CIRCUIT PROTECTION CHARACTERISTICS (page A-1 through A-4)

This table lists the circuit protective devices, with their Rockwell International part numbers, that are currently approved for use on the STS. Part numbers, dash numbers, current ratings, maximum applied loads, and minimum and maximum blow points are stated. The devices shown in this table need not be treated as an exclusive list of acceptable devices, but rather as a list of commonly used devices that are already approved for Orbiter use.

Detailed information about any military specification part may be obtained by referring to the applicable military standard.

Any device under consideration for use in the payload that is not shown in this table may be presented to the appropriate NASA safety board for review.

TABLE 2 - CURRENT-CARRYING CAPACITIES OF A SINGLE WIRE RATED AT 200^{O}C (392^{O}F) (page A-5)

This table shows the maximum current-carrying capacity of wires with insulation rated at 200^{O} C, that range in size from #1/0 AWG to #26 AWG, and that operate at sea level conditions or in vacuum at 200^{O} F and 72^{O} F ambient. The values shown were extrapolated from figures 3, 4, and 5 for easy reference. If wire with a rating of other than 200^{O} C is used, the maximum current-carrying capacity must be determined by use of figure 2.

5. SELECTION PROCESS

To use the tables and graphs in this document as an aid in selecting the proper wire size and circuit protection, one needs to know the:

Maximum continuous current the load is expected to draw.
Maximum voltage drop allowable between the protective device and load.
Length of the wire to and from the load.
Temperature rating of the wire insulation to be used.
Maximum ambient temperature in which the circuit will operate.
Ambient pressure (sea level, vacuum, or both) in which the circuit will operate.

After these parameters are established:

Select the appropriate protective device for the load involved using steps described in this section and table 1.

Use figure 1 as a guide to:

First, select the minimum wire size that is compatible with the protective device, considering the environmental conditions in which both the device and the wire will operate (including sea level conditions).

Then, find the minimum wire size that provides an acceptable voltage drop.

Choose the larger wire of the two above.

A step-by-step process is described in the following paragraphs, using figure 1 as a guide. To clarify the process an example using actual numbers has been included in appendix B.

STEP 1 - DETERMINE THE TYPE PROTECTION TO BE USED

The designer's choice of protective devices will be driven by consideration described in section 3.

STEP 2 - CHOOSE THE ENVIRONMENT IN WHICH THE PROTECTIVE DEVICE WILL OPERATE

If the circuit operates only at normal sea level conditions, a device may be selected without further calculation by choosing one with a "Min. Blow" (table 1) rating sufficient to carry the maximum continuous load current. The "Max. Blow" current for the chosen device must also be noted for use in later calculations.

However, since most payload circuitry must operate at sea level and in orbit, the maximum level of current the protective device can be required to carry is "Max. Appl. Load" based on the effects of zero-g and/or vacuum.

STEP 3 - SELECT THE RATING OF THE PROTECTIVE DEVICE

Using data in table 1 for Orbiter-type devices or corresponding data for other devices, select a device with a "Max. Appl. Load" sufficient to carry the maximum continuous load. Also note the value of "Max. Blow" for the selected device, that is the maximum sustained current the protective device can carry. The associated wire must be sized to carry this level of current continuously.

STEP 4 - CALCULATE THE MAXIMUM ALLOWABLE DT FOR THE WIRE INSULATION

Subtract the highest ambient temperature in which the wire will be active from the temperature rating of the wire insulation. This is the maximum allowable temperature rise of the insulation.

STEP 5 - DETERMINE THE MINIMUM WIRE SIZE FOR THE REQUIRED DT

If the circuit is energized only at sea level, use figure 3; otherwise, use figure 4 or 5, as appropriate, to determine the minimum allowable wire size. The wire selected must not cause the insulation temperature to exceed its rated value while carrying the highest sustained current ("Max. Blow") that the protective device can support.

This determination is made from figure 3, 4, or 5 by locating the value of "Max. Blow" in amperes for the protective device on the X-axis and moving vertically to the Maximum Allowable DT on the Y-axis. Choose the wire size at the intersection of the

two lines or the first size to the right of the intersection. This is the smallest wire that can be connected to the protective device selected in step 3 operating in the environment that was given.

STEP 6 - CALCULATE THE VOLTAGE DROP IN THE CHOSEN WIRE

Using resistance values listed in table 2 and the wire size selected above, calculate the voltage drop in the line (both supply and return). If the drop is within allowable limits, the wire selected above should be used. However, if the drop is too great, a larger wire must be used. Select the next larger size, refigure the drop, evaluate the results, and repeat until the smallest wire capable of providing a satisfactory voltage drop is determined.

STEP 7 - SELECT THE WIRE SIZE TO BE USED

The wire selected in step 6 is the proper wire to use in the circuit, and all other components of the circuit can remain unchanged.

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6. CURRENT-CARRYING CAPACITY OF INSULATED WIRES

Particular payloads may require that power be provided through pre-existing wires over which designers have no control. In such designs it becomes necessary to calculate the maximum amount of power that can be provided by individual wires under specified environmental conditions. It may also be necessary to select the proper wire protection after wire limitations have been established. In anticipation of these requirements, figure 2, and the following annotated steps have been provided to aid designers in their calculations.

To determine the current-carrying capacity of an insulated wire, one must know the:

Ambient pressure in which the circuit will operate.
Maximum ambient temperature at which the circuit will operate.
Wire temperature rating.
Wire size.

After these parameters are established:

Determine the maximum temperature rise allowable for the particular wire insulation being used.

Determine the current-carrying capacity of the wire based on the ambient temperature and pressure of the operating environment.

If required, select the proper protective device.

A step-by-step process is described in the following paragraphs, using figure 2 as a guide. To clarify the process an example of using actual numbers has been included in appendix B.

STEP 1 - FIND THE MAXIMUM ALLOWABLE DT FOR THE WIRE INSULATION

Subtract the maximum temperature at which the circuit will operate from the manufacturer's thermal rating (or specification limit) of the wire insulation. This is the temperature rise caused by current flow and represents the maximum allowable DT for this insulation.

STEP 2 - FIND THE MAXIMUM ALLOWABLE CURRENT FOR THE WIRE

Use figure 3, 4, or 5 as appropriate for the ambient pressure and temperature in which the wire will operate, locate the DT on the Y-axis and follow this line horizontally until it intersects the line for the wire size in question, and then drop vertically to read the current off the X-axis. This is the level of current that will provide the DT found in step 1 and is the maximum current a single wire of the size specified should carry in this environment.

STEP 3 - SELECT THE CIRCUIT PROTECTIVE DEVICE

Table 1 is used to select a suitable protective device. Any device with a "Max. Blow" current at or below the level calculated from step 2 is suitable. The choice between fuse, circuit breaker, or RPC may be based on considerations described in section 3.

The maximum current that the protected wire can be required to carry in a properly designed circuit, then, is the "Max. Appl. Load" of the device selected.

Special Note:

When only two wires are used in parallel to provide greater current-carrying capacity and are bused on both ends, they must be individually protected on the source end only. If, however, more than two wires are bused, they must all be individually protected on both ends. This requirement is illustrated in figure 7.

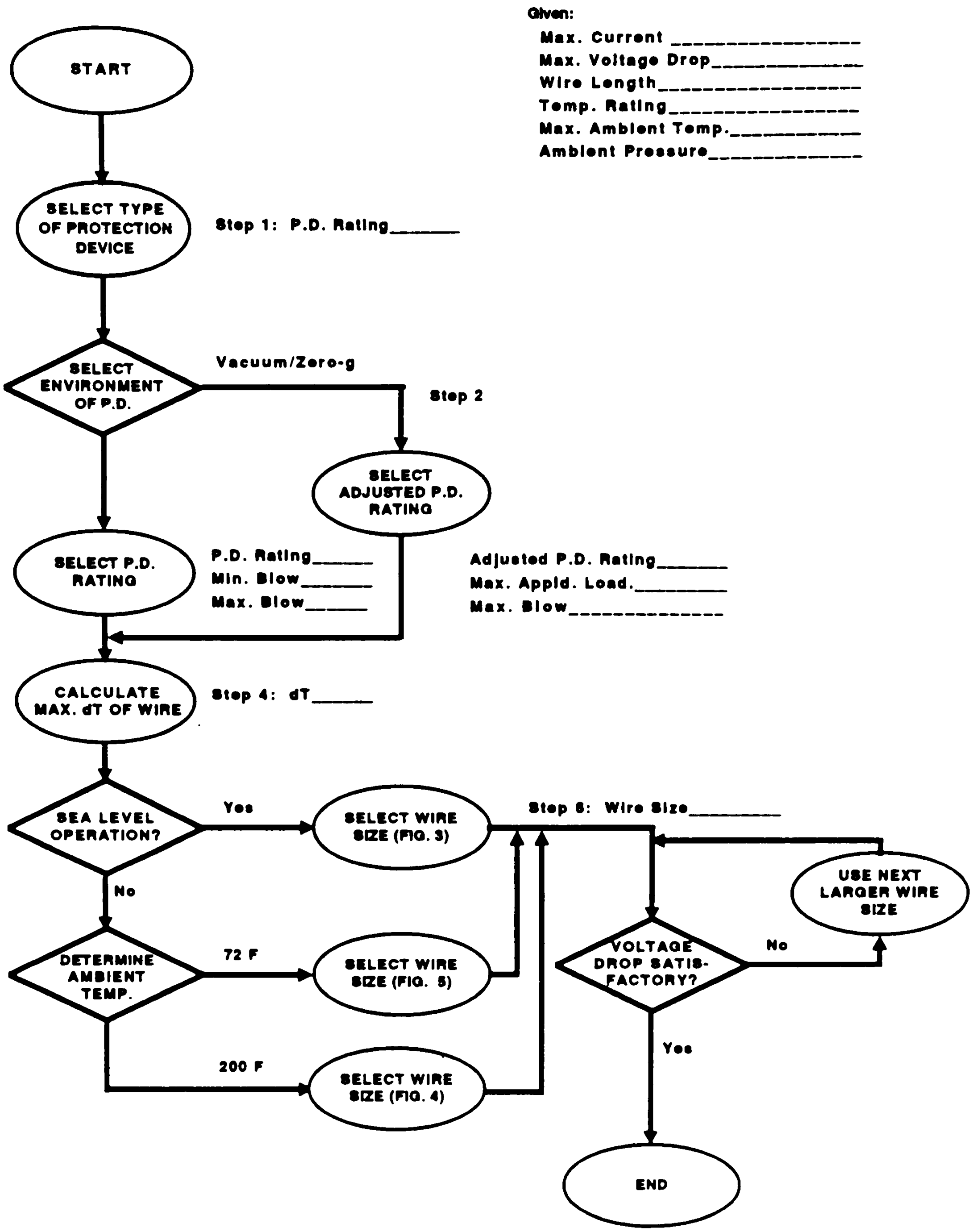

Figure 1. Selection of Wire Size and Circuit Protection Device

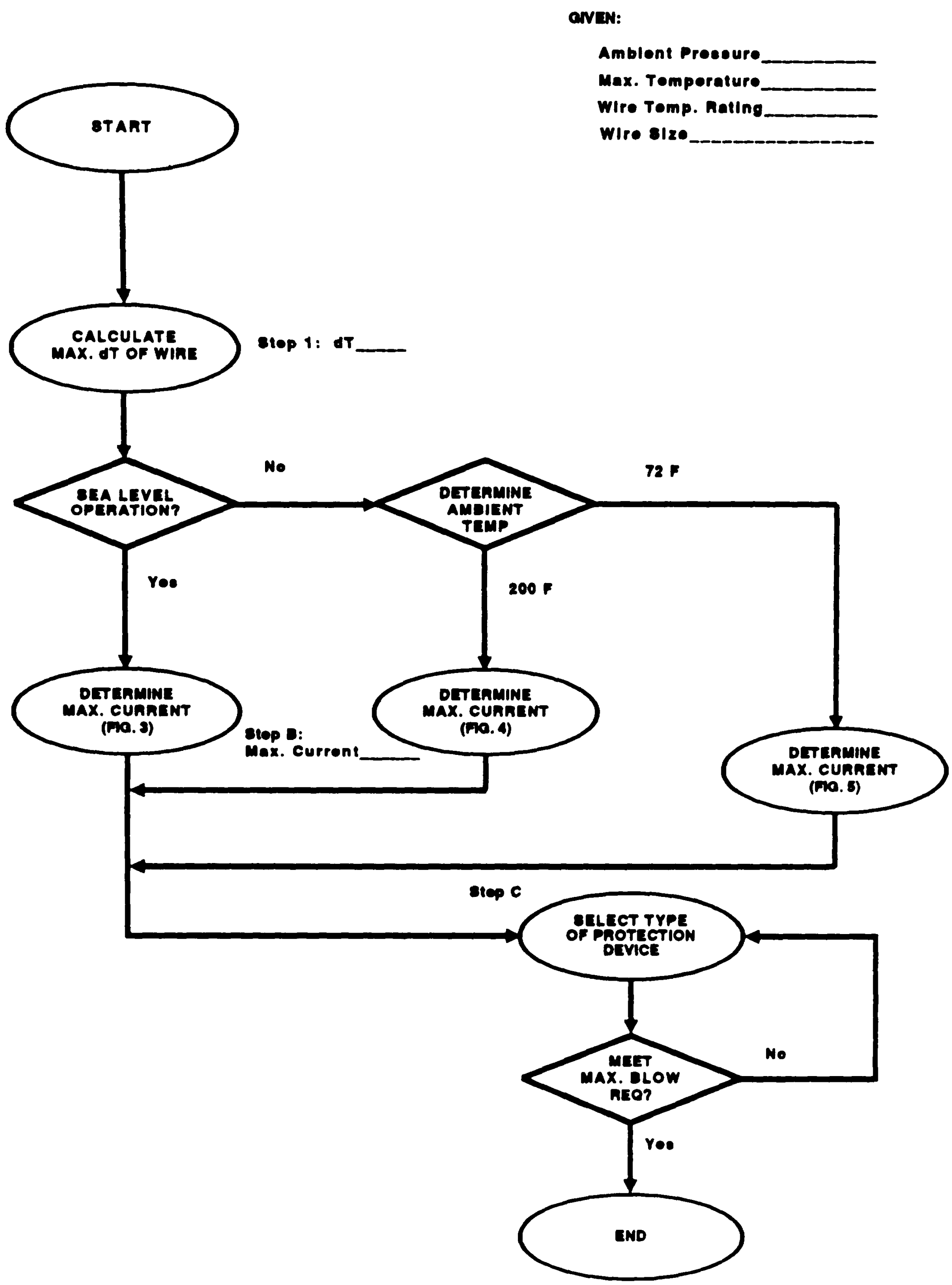

Figure 2. Current-Carrying Capacity of Insulated Wire

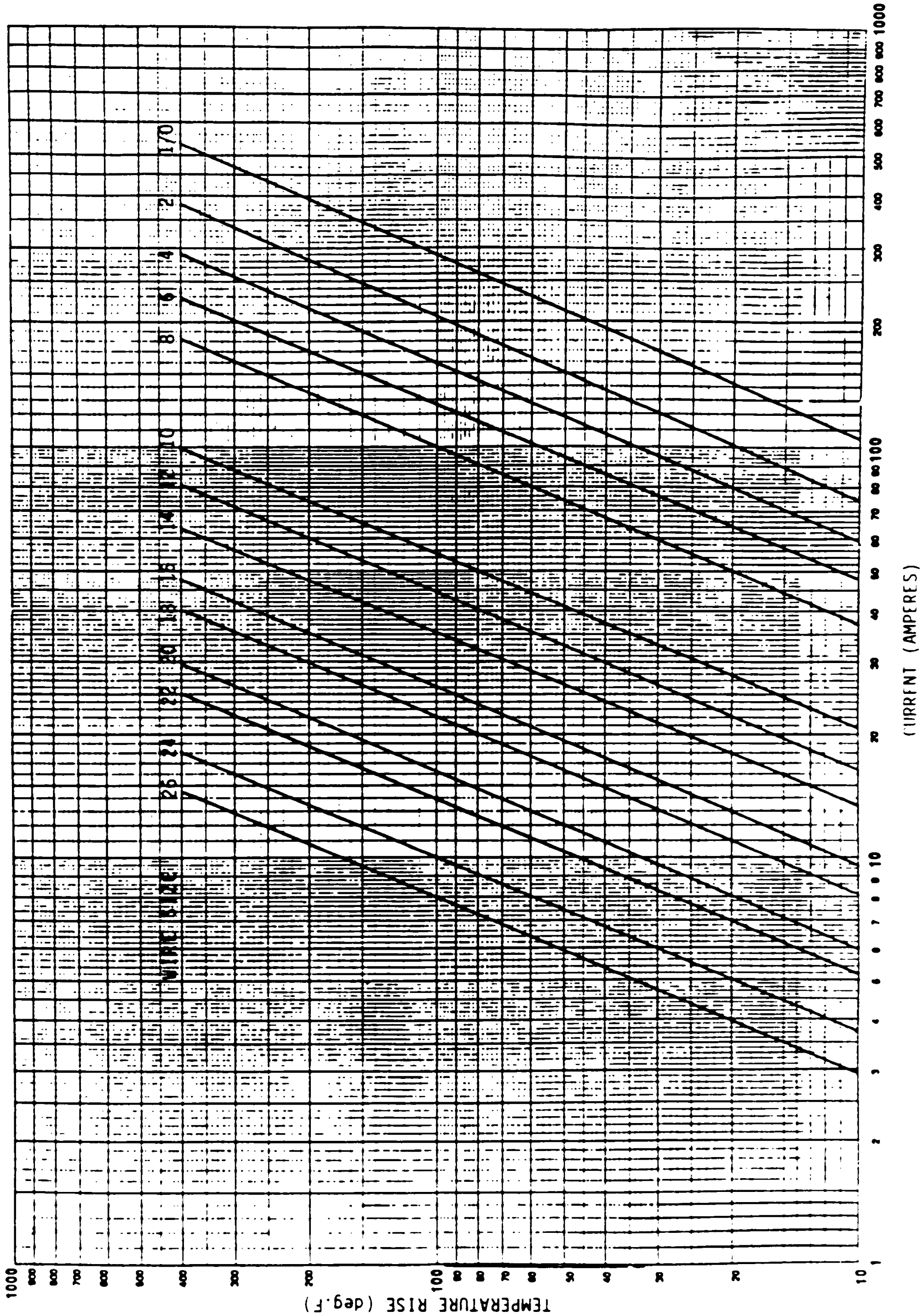

Figure 3. Single Wire in Free Air

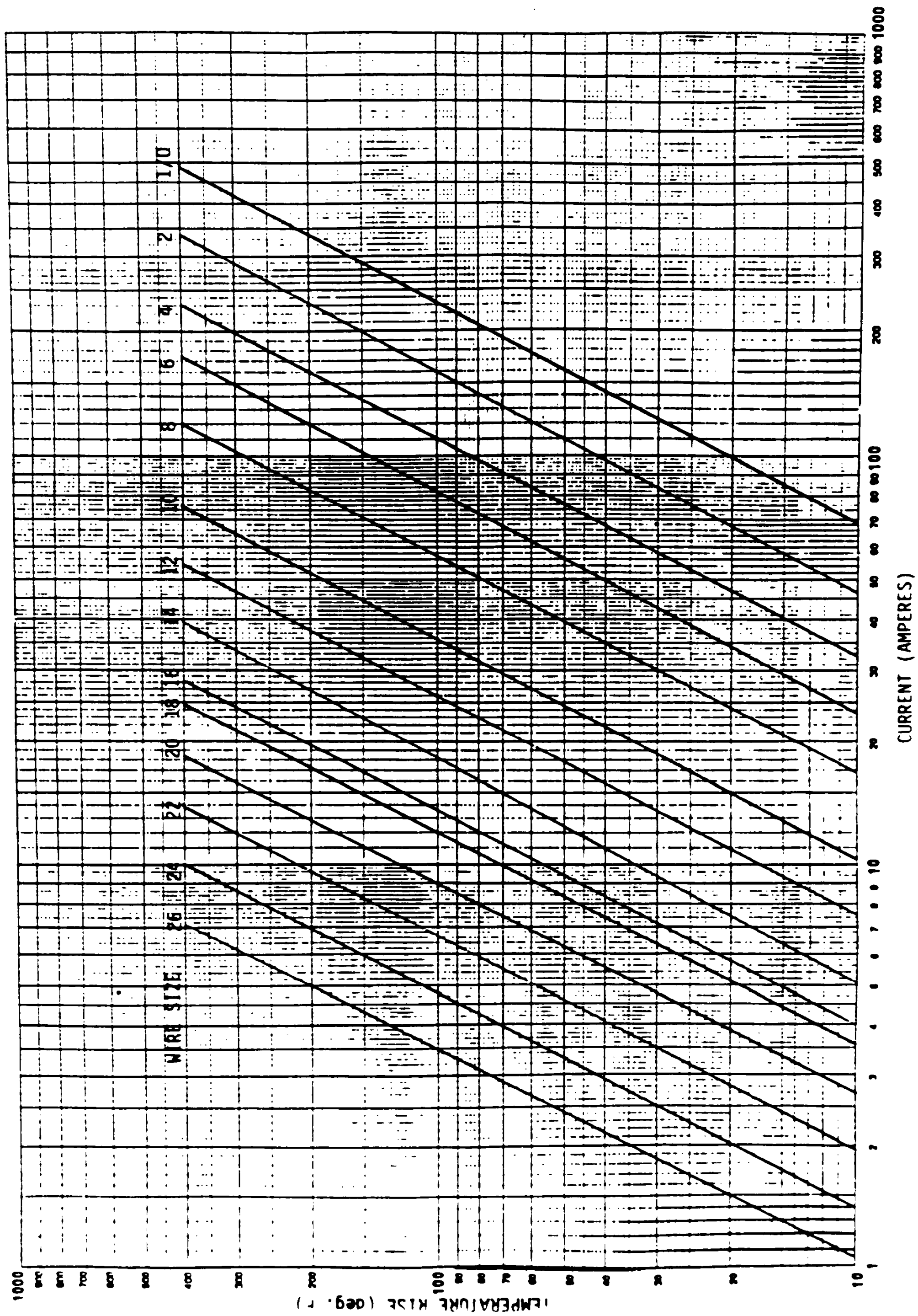

Figure 4. Single Wire in a Vacuum at 200°F Ambient

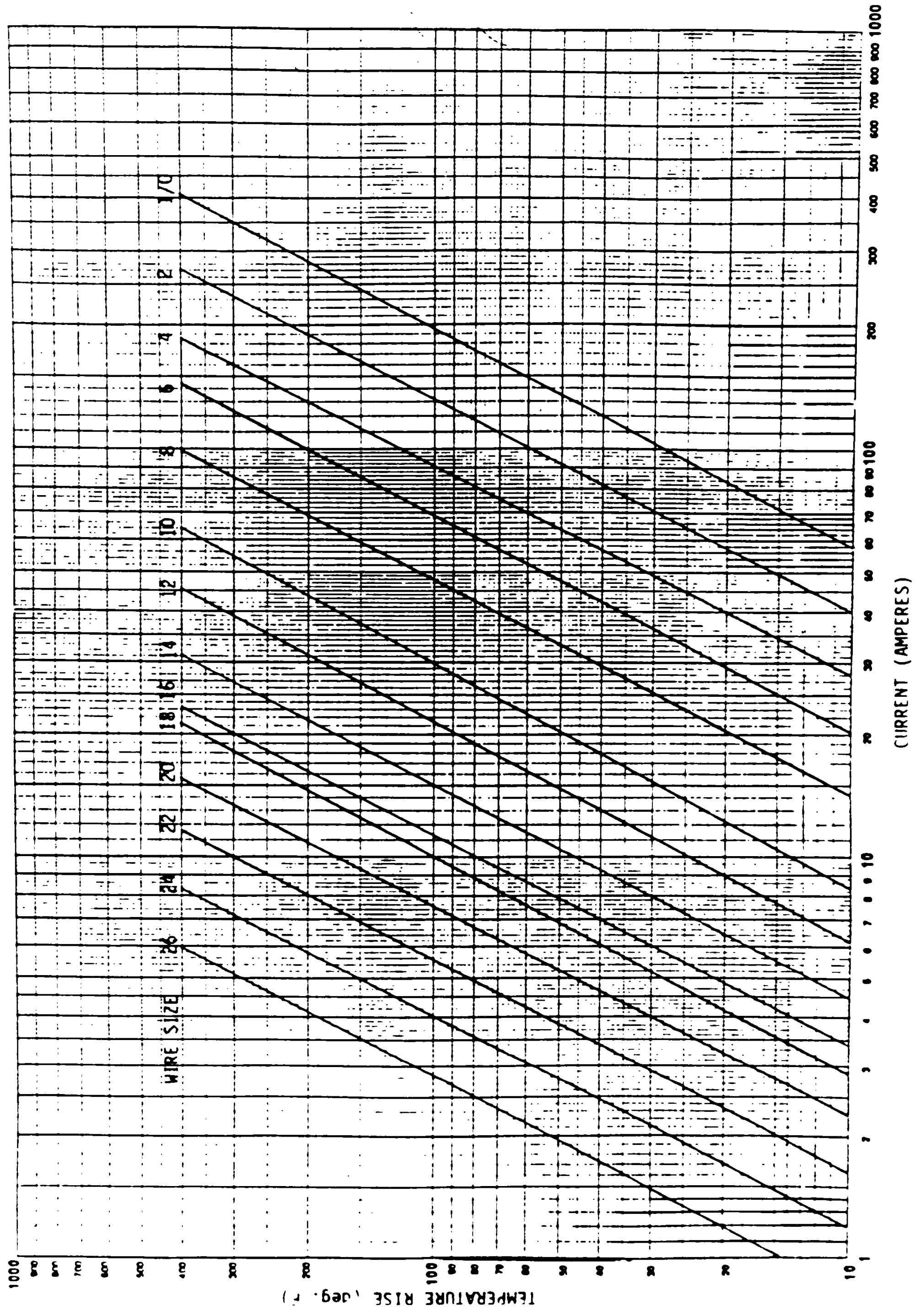

Figure 5. Single Wire in a Vacuum at 72°F Ambient

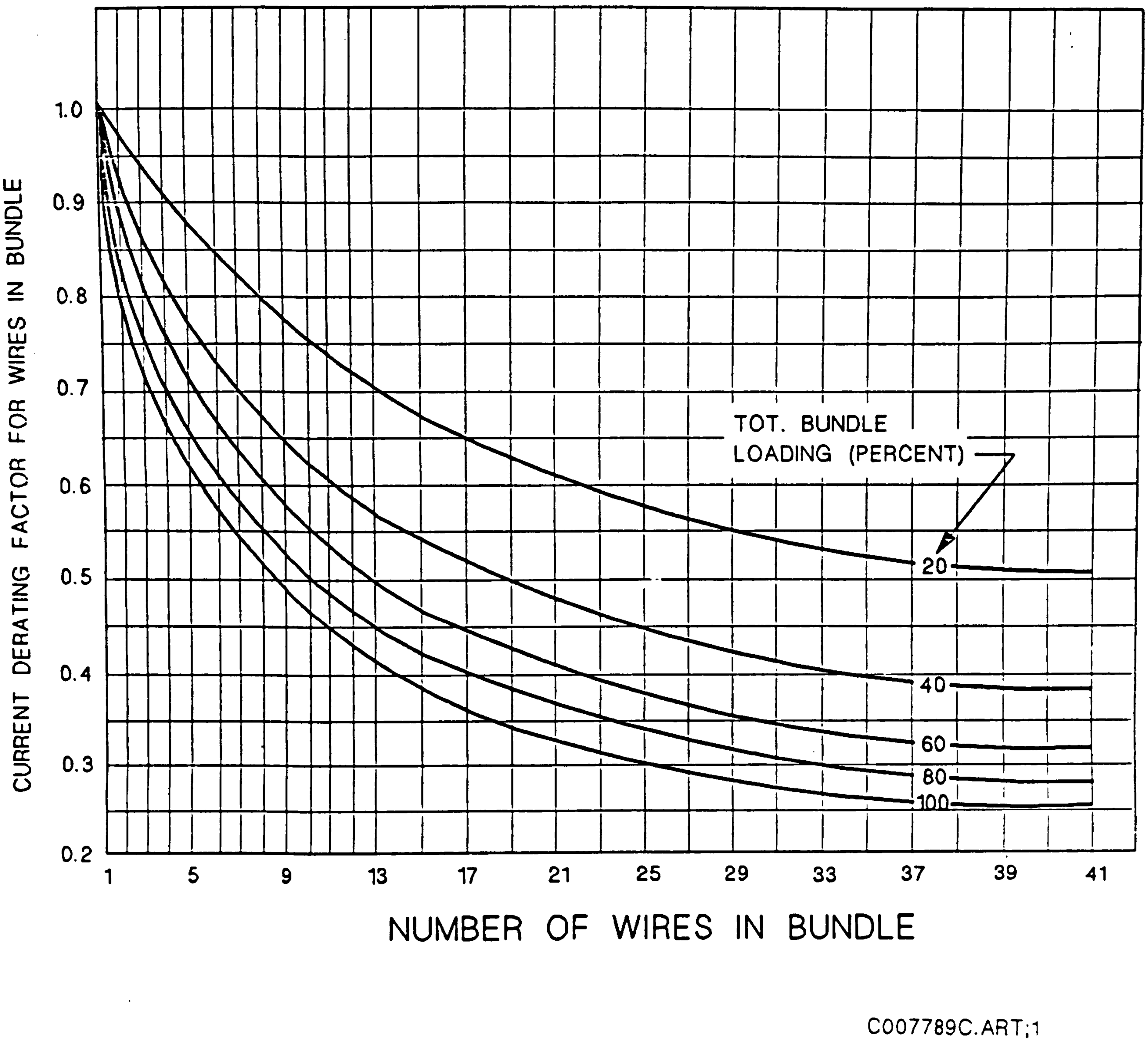

Figure 6. MIL-W-5088(K) Bundle Derating Curves

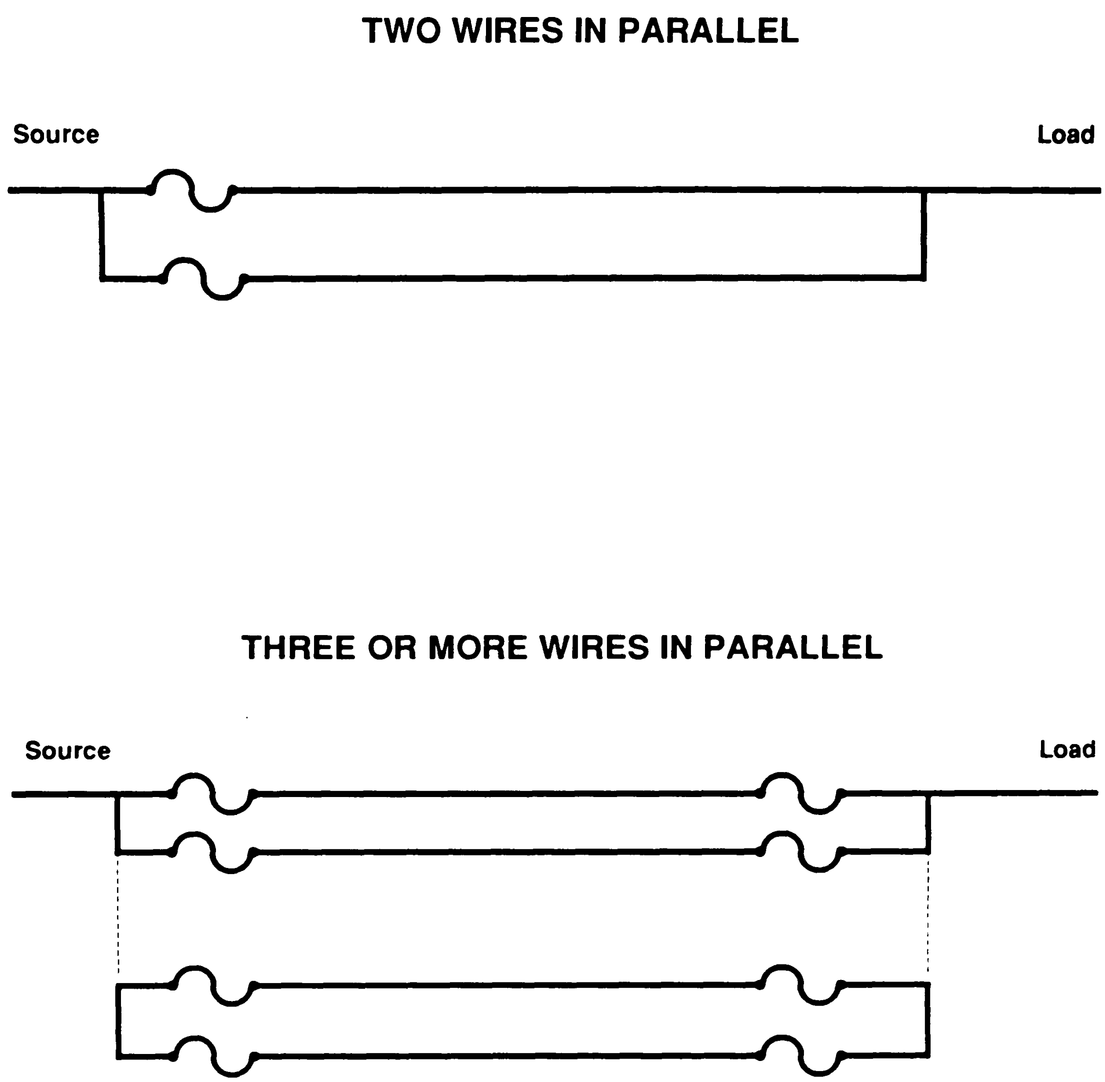

Figure 7. Protection of Parallel Power Wires

APPENDIX A
TABLES

TABLE 1 - ORBITER CIRCUIT PROTECTION CHARACTERISTICS

FUSE, SUBMINIATURE PLUG-IN (ME451-0018-XXXX)

DASH #	Rating (amps)	Min. Blow (100%)	Max. Appl. Load (50%)	Max. Blow (150%)
0012	0.125	0.125	0.0625	0.188
0025	0.25	0.25	0.125	0.375
0050	0.50	0.50	0.25	0.75
0075	0.75	0.75	0.375	1.125
0100	1.00	1.00	0.50	1.50
0150	1.50	1.50	0.75	2.25
0200	2.00	2.00	1.00	3.00
0300	3.00	3.00	1.50	4.50
0400	4.00	4.00	2.00	6.00
0500	5.00	5.00	2.50	7.50
0750	7.50	7.50	3.75	11.25
1000	10.00	10.00	5.00	15.00

FUSE, SMALL WITH AXIAL LEADS (ME451-0010-XXXX)

DASH #	Rating (amps)	Min. Blow (100%)	Max. Appl. Load (50%)	Max. Blow (150%)
1001	0.125	0.125	0.0625	0.188
1002	0.25	0.25	0.125	0.375
1005	0.50	0.50	0.250	0.750
1007	0.75	0.75	0.375	1.125
1010	1.00	1.00	0.500	1.50
1015	1.50	1.50	0.750	2.25
1020	2.00	2.00	1.00	3.00
1030	3.00	3.00	1.50	4.50
1040	4.00	4.00	2.00	6.00
1050	5.00	5.00	2.50	7.50
1070	7.00	7.00	3.50	10.50
1100	10.00	10.00	5.00	15.00

TABLE 1 - ORBITER CIRCUIT PROTECTION CHARACTERISTICS (Continued)

FUSE, CARTRIDGE (ME451-0009-XXXX)

DASH #	Rating (amps)	Min. Blow (100%)	Max. Appl. Load (50%)	Max. Blow
1023	0.5	0.5	0.25	0.75 (150%)
1001	1.0	1.0	0.50	1.50 (150%)
1002	2.0	2.0	1.00	3.00 (150%)
1003	3.0	3.0	1.50	4.50 (150%)
1021	5.0	5.0	2.50	6.75 (135%)
1019	7.5	7.5	3.75	10.12 (135%)
1005	10.0	10.0	5.0	13.50 (135%)
1006	15.0	15.0	7.50	20.25 (135%)
1007	20.0	20.0	10.00	27.00 (135%)
1008	25.0	25.0	12.50	33.75 (135%)
1009	30.0	30.0	15.00	40.50 (135%)

FUSE, LARGE, REGULAR BLOW (ME451-0016-XXXX)

DASH #	Rating (amps)	Min. Blow (110%)	Max. Appl. Load (100%)	Max. Blow
2035	35.0	38.5	35.0	59.50 (170%)
2050	50.0	55.0	50.0	85.0 (170%)
2080	80.0	88.0	80.0	188.0 (235%)
2100	100.0	110.0	100.0	235.0 (235%)
2125	125.0	137.5	125.0	250.0 (200%)
2150	150.0	165.0	150.0	300.0 (200%)
2200	200.0	220.0	200.0	400.0 (200%)

FUSE, SLOW BLOW (ME451-0016-XXXX)

DASH #	Rating (amps)	Min. Blow (110%)	Max. Appl. Load (100%)	Max. Blow (240%)
3035	35.0	38.5	35.0	84.0
3050	50.0	55.0	50.0	120.0
3150	150.0	165.0	150.0	360.0
3200	200.0	220.0	200.0	480.0

TABLE 1 - ORBITER CIRCUIT PROTECTION CHARACTERISTICS (Continued)

CIRCUIT BREAKER (MC454-0026-XXXX)

DASH #	Rating (amps)	Min. Blow (110%)	Max. Appl. Load (95%)	Max. Blow (145%)
2010	1.0	1.10	0.95	1.45
2020	2.0	2.20	1.90	2.90
2030	3.0	3.30	2.85	4.35
2050	5.0	5.50	4.75	7.25
2075	7.5	8.25	7.125	10.87
2100	10.0	11.00	9.50	14.50
2150	15.0	16.50	14.25	21.75
2200	20.0	22.00	19.00	29.00

CIRCUIT BREAKER, 3 PHASE AC (MC454-0032-XXXX)

DASH #	Rating (amps)	Min. Blow (110%)	Max. Appl. Load (95%)	Max. Blow (145%)
3030	3.00	3.30	2.85	4.35

REMOTE POWER CONTROLLER (MC450-0017-XXXX)

DASH #	Rating (amps)	Min. Blow (125%)	Max. Appl. Load (100%)	Max. Blow (150%)
1030	3.0	3.75	3.0	4.50
1050	5.0	6.25	5.0	7.50
1075	7.5	9.375	7.5	11.25
1100	10.0	12.50	10.0	15.00
1150	15.0	18.75	15.0	22.50
1200	20.0	25.00	20.0	30.00

DEFINITION OF TERMS FOR TABLE 1

Rating - Manufacturer's sea level ambient rating of device.

Min. Blow - Maximum Blow is the guaranteed minimum level of current at which the device can open. All devices can carry any level of current below this amount indefinitely and never open.

Max. Blow - Maximum Blow is the guaranteed maximum level of current required to cause the device to open. Some devices may be able to carry up to this level of current indefinitely without opening.

Note:

To comply with specifications, a device must operate, or open, at some current level between "Min. Blow" and "Max. Blow." The difference in levels is the manufacturing tolerance.

Max. Appl. Load - Maximum Applied Load is the maximum level of current which can be required form the device in a properly designed circuit. This figure represents the device capability when derated for zero-g (or vacuum) operation.

TABLE 2 - CURRENT CARRYING CAPACITIES OF A SINGLE WIRE RATED AT 200^{O}C (392^{O}F)

Conditions: 72 deg.F/14.7psi MBO150-048 Kapton Wire Resistances

Gauge #	Max. Current (amps)	OHMS/FT.
1/0	470.0	0.000113
2	341.0	0.000177
4	267.0	0.000275

6	211.0	0.000436
8	169.0	0.000694
10	91.0	0.001240
12	74.0	0.001980
14	60.0	0.003000
16	43.0	0.004760
18	37.0	0.006100
20	27.0	0.009770
22	23.0	0.016000
24	16.4	0.030100
26	13.2	0.049400

Conditions: 72 deg.F/1*10^{-6}TORR MBO 150-048 Kapton Wire Resistances

Gauge #	Max. Current (amps)	OHMS/FT.
1/0	361.1	0.000113
2	245.8	0.000177
4	171.6	0.000275
6	128.9	0.000436
8	88.4	0.000694
10	56.2	0.001240
12	40.9	0.001980
14	28.7	0.003000
16	21.4	0.004760
18	19.1	0.006100
20	13.9	0.009770
22	10.4	0.016000
24	7.5	0.030100
26	5.3	0.049400

Conditions: 200 deg.F/1*10^{-6}TORR MBO 150-048 Kapton Wire Resistances

Gauge #	Max. Current (amps)	OHMS/FT.
1/0	332.0	0.000146
2	225.0	0.000229
4	157.0	0.000355
6	118.0	0.000563
8	81.0	0.000896
10	51.0	0.001601
12	37.0	0.002700
14	26.0	0.004240
16	20.0	0.006450
18	17.0	0.008350
20	13.0	0.012750
22	9.5	0.023500
24	6.8	0.035200
26	4.8	0.061281

APPENDIX B

EXAMPLES

EXAMPLE 1

SELECTING A PROTECTIVE DEVICE AND ASSOCIATED WIRE

Established parameters and data:

Maximum continuous load current - 12 amps

Maximum allowable voltage drop - 500 mv

Length of wire - 20 feet (power and return)

Temperature rating of wire - 200^{O}C (392^{O}F)

Maximum ambient operating temperature - 200^{O}F

Ambient operating pressure - 1 x 10^{-6} TORR

SELECTION PROCESS

STEP 1 - SELECT THE TYPE PROTECTION

Using information in section 3, a cartridge fuse has been selected for this application.

STEP 2 - IDENTIFY THE OPERATING ENVIRONMENT OF THE PROTECTIVE DEVICE

The initial information states that the device must operate in a vacuum; however, it will also operate at sea level conditions during checkout.

STEP 3 - SELECT THE RATING OF THE PROTECTIVE DEVICE

Referring to table 1, Cartridge Fuse no. ME451-0009-1008 has a "Max. Appl. Load" of 12.5 amps. This is the smallest of this type fuse that will, when derated for vacuum, handle the 12-amp load. The "Max. Blow" current of 33.75 amps will be used to determine wire size.

STEP 4 - CALCULATE THE MAXIMUM ALLOWABLE DT FOR THE WIRE INSULATION

Subtract the maximum operating temperature from the wire rating:

$$392^{O}F - 200^{O}F = 192^{O}F$$

STEP 5 - DETERMINE THE MINIMUM WIRE SIZE FOR THIS DT

Using figure 4, locate the "Max. Blow" current (33.75 amps) from step 3 on the X-axis and the DT (192^{O}F) from step 4 on the Y-axis and draw lines to their intersection. The first wire size to the right of the intersection is #12 AWG. This is the size of a suitable wire in this environment with the protection chosen in step 2.

STEP 6 - CALCULATE THE VOLTAGE DROP IN THE WIRE

Multiply the resistance per foot of #12 AWG wire at 200^{O}F in a vacuum (0.002700 ohms) from table 2 by the length (20ft) to find the total resistance of the path and multiply that by the operating current (12 amps) to find the total voltage drop.

$$0.002700 \text{ X } 20 \text{ X } 12 = 648 \text{ mv}$$

This value is greater than the 500 mv limit; consequently, a larger wire must be used to accommodate the allowable voltage drop. The next larger size is #10 AWG which has a resistance of 0.001601 ohms/foot (table 2). Find the voltage drop using a #10 AWG wire:

$$0.001601 \text{ X } 20 \text{ X } 12 = 384 \text{ mv}$$

STEP 7 - SELECT THE WIRE SIZE TO BE USED

The 384 mv drop is below the 500 mv limit; therefore, the proper wire for this application is #10 AWG.

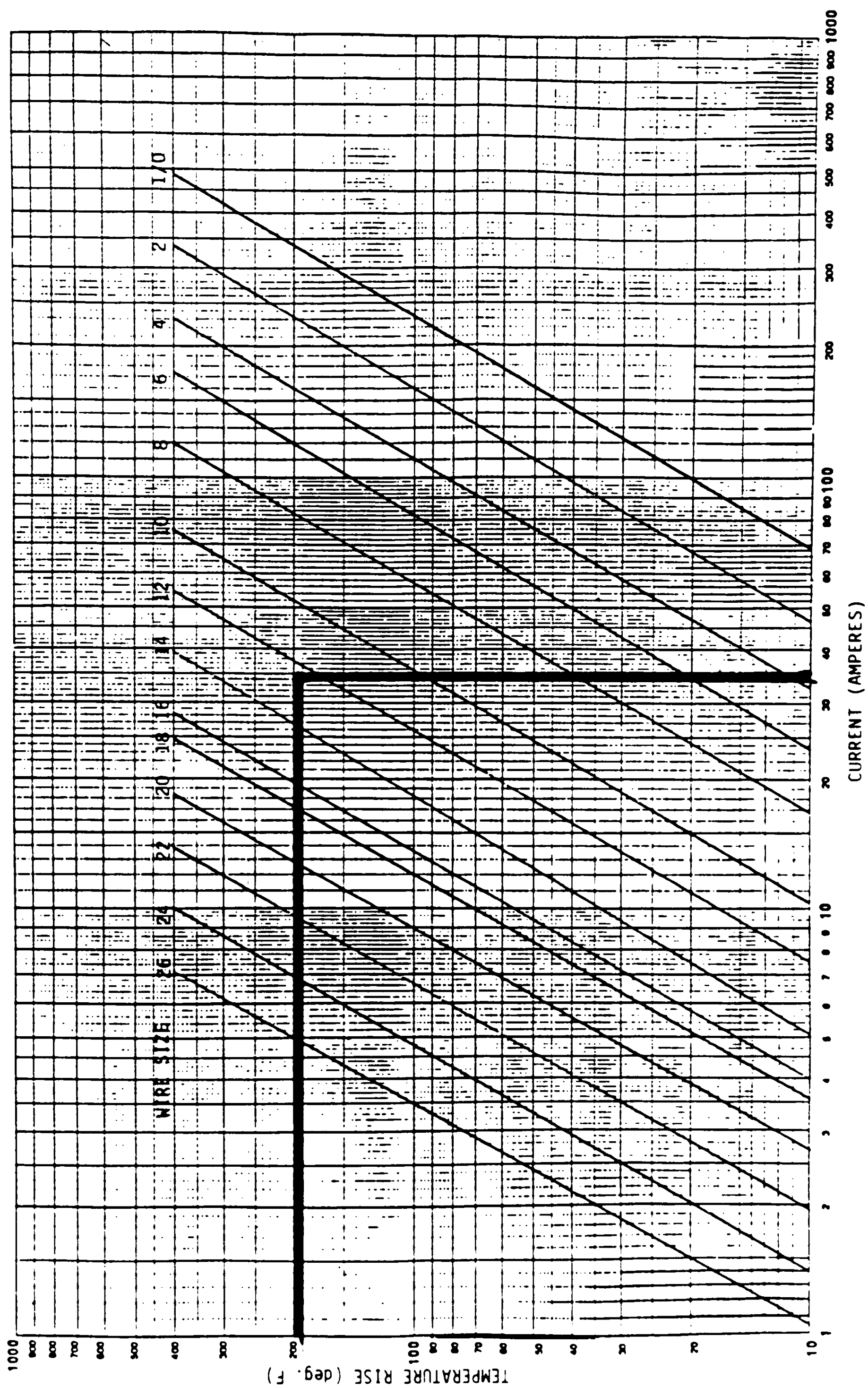

Figure 4. Single Wire in a Vacuum at 200°F Ambient

EXAMPLE 2

CALCULATING THE CURRENT-CARRYING CAPACITY OF A WIRE

Established parameters and data:

Ambient pressure - Vacuum

Maximum temperature - 72^{O}F

Wire temperature rating - 180^{O}C (359^{O}F)

Wire size - 22 AWG

SELECTION PROCESS

STEP 1 - FIND THE MAXIMUM ALLOWABLE DT

Subtract the maximum operating temperature from the wire rating.

$$359^{O}F - 72^{O}F = 287^{O}F$$

STEP 2 - FIND THE MAXIMUM CURRENT FOR A SINGLE WIRE CONFIGURATION

Using figure 5, follow DT (287 ^{O}F) on the Y-axis to its intersection with the 22 AWG line and read 9.9 amps on the X-axis.

STEP 3 - SELECT THE PROTECTIVE DEVICE

Several devices listed in table 1 can be used for protection:

DEVICE	RATING amps	MAX. BLOW amps	MAX. APPL. LOAD amps
Cartridge Fuse	5	6.75	2.5
Circuit Breaker	5	7.25	4.75
RPC	5	7.5	5.0

The maximum continuous current that can safely be delivered by this wire when it is properly protected can be obtained by the use of an RPC (5.0 amps).

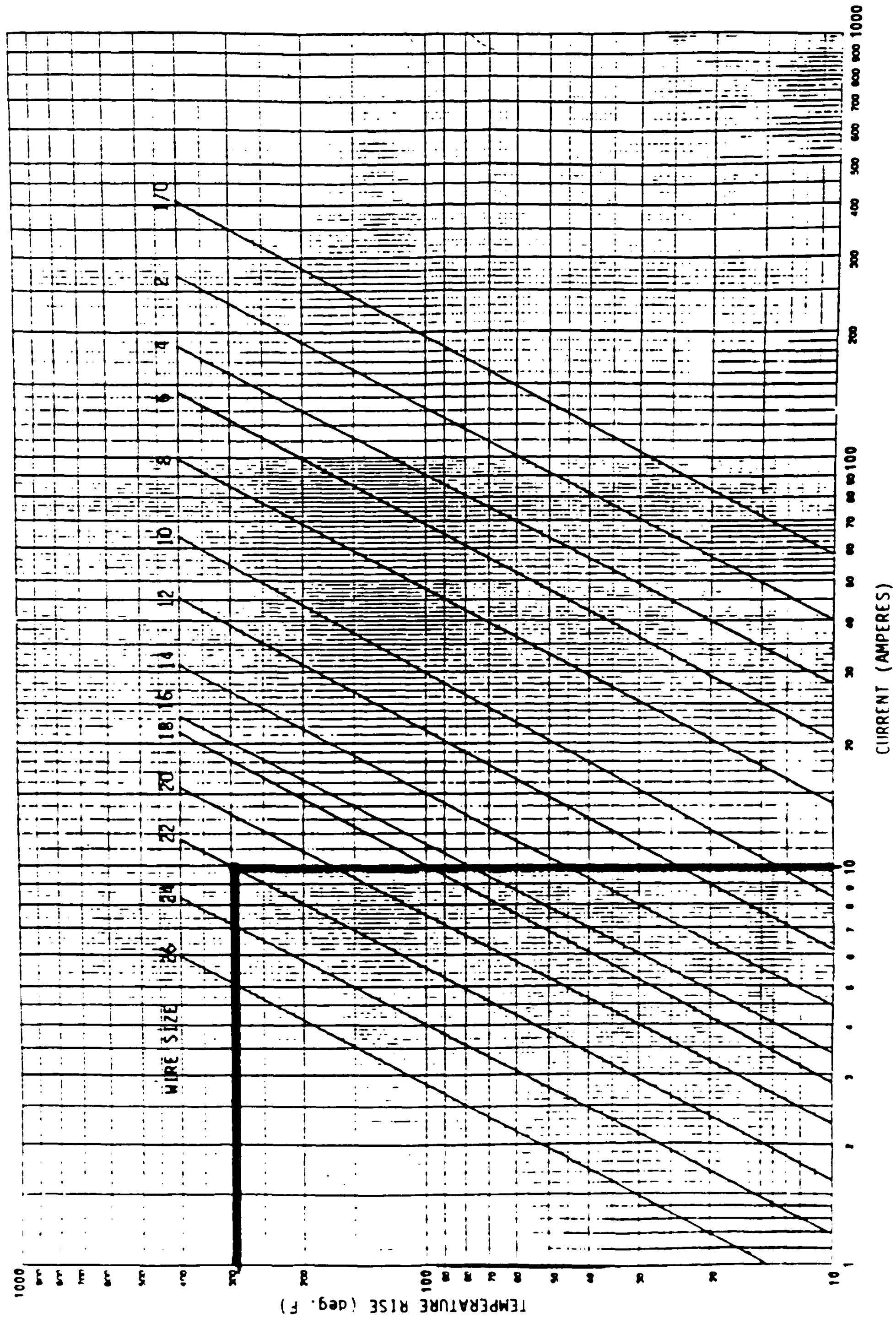

Figure 5. Single Wire in a Vacuum at 72°F Ambient

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16. Abstract

Electrical designers of Orbiter payloads face the challenge of determining proper circuit protection/wire size parameters to satisfy Orbiter engineering and safety requirements. This document is the result of a program undertaken to review test data from all available aerospace sources and perform additional testing to eliminate extrapolation errors. The resulting compilation of data was used to develop guidelines for the selection of wire sizes and circuit protection ratings. The purpose of this document is to provide guidance to the engineer to ensure a design which meets Orbiter standards and which should be applicable to any aerospace design.

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