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TECHNIQUE AND MEASUREMENT OF
HEAT FLUX AND FLAME TEMPERATURE
IN ROCKET PLUME EXPOSURES

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J. R. Piergallini and A. M. Stoll
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

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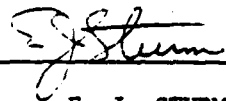
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subject to the rocket engine plume. To this end an investigation was performed using model rocket static test engines simulating full scale rocket engine firings with instrumented live animals, heat flux transducers and thermocouples for burn injury assessments. Available data on rocket engine flame temperatures was either extrapolated or computed from chemical compositions and because of the unique "dirty" characteristics of the flame, it was necessary to devise special instrumentation for direct measurements. A heat flux transducer was fabricated to measure the energy impinging upon the skin surface at various distances from the rocket engine. The transducer was calibrated against a graphite imaging furnace capable of producing 15 cal/cm² sec, in conjunction with a standard radiation source and radiometer. Radiometric observations were used also to describe precisely the pulse shape of the rocket engine plume. External and intradermal thermocouples measured the actual temperatures experienced in producing a white burn in the rat (equivalent to a second degree burn in the human) and for monitoring each test and correlating one exposure with another. This paper describes the techniques and measurements used, the generation of a time-temperature profile for producing the standard burn effect and provides a temperature history at the level of the burn site. These measurements, together with the observed burn effects, applied to tissue damage information available from earlier work provide the necessary data base for design and modification of seat trajectories to avoid burns.

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INTRODUCTION

With the advent of multiple ejections of aircrewmembers from Naval aircraft, in tandem and multiple cabin sequenced escape systems, the need arose for assessment of burn injury hazard due to exposure to the rocket plume. A suitable experimental laboratory test with associated instrumentation was required to simulate full-scale ejection seat firing, thus providing design data for prediction of burn injury. Such prediction required measurements of heat flux and flame temperature in relation to the proximity of the subject to the rocket engine plume. Thus far engine flame temperatures were either extrapolated or computed from chemical compositions. Because of this and the unique "dirty" characteristics of the flame, it was necessary to devise special instrumentation for direct measurements. The model rocket static test engine, Estes No. B4-0(P), was selected to provide the environmental simulation because of its characteristic similarities to full-scale rocket engines. A heat flux transducer was fabricated to measure the energy impinging upon the surface of the skin for these exposures. This transducer was calibrated against a graphite imaging furnace, capable of producing 15 cal/cm² sec, and a laboratory radiometer. Radiometric observations were used to describe precisely the pulse shape of the rocket engine plume. This paper describes the techniques and measurements used, generates a time-temperature profile for producing the standard burn effect and provides a temperature history at the level of the burn site. These measurements applied to tissue damage information available from earlier work provide the necessary data base for design of seat trajectories to avoid burns.

MATERIALS AND METHOD

The experimental apparatus consists of a piece of transite material with an aperture through which the rocket engine plume is emitted (Fig 1). The apparatus is explained fully in reference 1. Either a male Wistar rat or a heat flux transducer was placed behind the aperture for assessment of burn hazard predictions. External and intradermal thermocouples measured the actual temperatures experienced in producing a standard white burn in the rat (equivalent to a minimal second degree burn in the human) and for monitoring each test and correlating one exposure with another. The monitor thermocouple was epoxied to the front surface of the transite shield adjacent to the aperture in order to measure the relative intensity of each rocket engine exposure. This monitor thermocouple correlates the energy transmitted through the shield aperture for either the rat or transducer because both cannot be exposed simultaneously. A graph of the voltage output of the monitor thermocouple versus the voltage output of the heat flux transducer was constructed. In this manner the precise energy impinging upon the

aperture of the transite shield could be established for exposures on the live rat in terms of the heat flux transducer output. The heat flux transducer was fabricated from a piece of 0.159cm thick copper sheet cut 0.045cm long and 0.043cm wide. A small hole was drilled into the center back of the copper sheet resulting in a weight of 0.235g. A 30 gauge copper-constantan thermocouple was soft soldered into the hole. The copper calorimeter was imbedded in an asbestos sheet and secured with aluminum oxide cement. The monitor thermocouple was constructed from 24 gauge chromel-alumel thermocouple wire. The intradermal thermocouple was inserted beneath the skin of the rat by first inserting a hypodermic needle through the skin and then threading a 40 gauge copper-constantan thermocouple through the needle and finally withdrawing the needle leaving the thermocouple wire in place. A Thermotronics Isotronic Radiometer, Gardon Type, was placed perpendicular to the rocket engine blast to describe the profile and duration of the pulse. All of the above transducer voltage outputs were recorded on two Honeywell Electronik 196 Lab recorders. The only transducer necessitating calibration thus far was the copper calorimeter and this was accomplished by first exposing a laboratory standard radiometer, an RD F Corporation Model CFR-1A, to a Compound Thermal-Imaging System (2) producing a square wave radiation pulse. The copper calorimeter was subsequently exposed to an identical pulse which varied in intensity from 1.5 to 12.3 cal/cm² sec for a one second duration. Voltage outputs were monitored on a Hewlett Packard 3490A Digital Voltmeter and recorded on a Hewlett Packard 3489A Data Punch. This provided a calibration constant for the copper calorimeter so that absolute values of energy impinging upon the transite shield aperture could be provided for exposures at varying distances and intensities from the rocket engine plume. Next, live rats were exposed in order to find the exact distance and energy that produced the standard white burn effect. Because these measurements would be difficult to reproduce in an actual ejection seat firing, an additional system or procedure was necessary for predicting burn hazard injury. A 30 gauge copper-constantan thermocouple was substituted for the rat at the standard white burn injury site so that the indicated temperature rise can be used in the field for burn hazard predictions in humans. To further describe the actual temperatures at the burn site, three additional thermocouples of different gauges were placed across the aperture hole of the transite shield to provide for extrapolation to the true temperature at the level of the burn site. The four thermocouples were calibrated by a Cohu Model 324A DC Voltage Calibrator in series with each thermocouple; voltage output was recorded on a Honeywell 1508 Visicorder.

RESULTS AND DISCUSSION

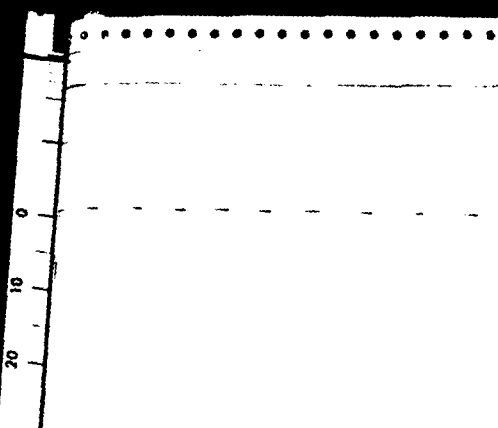
The Wistar rats were subjected to 34 exposures with the rocket engine plume at distances ranging from 9in (22.9cm) to 19in (48.3cm). Exposures at the 16in (40.6cm) distance produced the standard white burn effect. Placing the heat flux transducer (copper calorimeter) at the same exposure distance indicated a heat flux measurement of 1.84 cal/cm² sec. Similarly the 30 gauge copper-constantan thermocouple indicated a temperature of 208°C (406°F). The total pulse duration was from 1.0 to 1.1 sec corresponding to a square wave pulse of approximately 0.6 sec, the determination of which is explained in detail in reference 1. Fig 2 shows the estimated time-temperature profile for producing a blister in a human for short exposure times as related to the output from a 30 gauge thermocouple. Reference 1 fully explains the development of this curve. Referring to Fig 2, all points falling to the left of the line would indicate injury less than a minimal second degree burn in a human and all points falling to the right of the line, second degree, or worse. Table 1 shows the change in temperature from room temperature (23.1°C) at 0.1 sec increments for a rocket plume exposure at 16in (40.6cm) for four increasingly larger diameter thermocouples. It is possible to generate a computer solution for estimating the actual temperature by reducing the diameter of the thermocouple wire to approach zero. The difference in output of each thermocouple is attributable to its time constant and reradiation.

SUMMARY AND CONCLUSIONS

Using miniature rocket engines and live animals to simulate the burn hazard due to ejection seat rocket plume flames, valid data was obtained by fabricating a copper calorimeter and calibrating it to a laboratory standard radiometer. A time-temperature profile for producing the standard burn effect in a human was generated from thermocouple and calorimeter data. In addition a temperature history at the level of the burn site using a 30 gauge thermocouple was presented with additional data for formulating actual temperatures impinging upon human skin causing a minimal second degree burn. Temperature measurements at different sites within the cockpit may be used in conjunction with these data in the design of seat systems to avoid thermal injury in multiple ejections.

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FIGURE 1 - Rocket Plume Exposure Apparatus



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Estimated Time to Blister at Indicated Flame Temperature

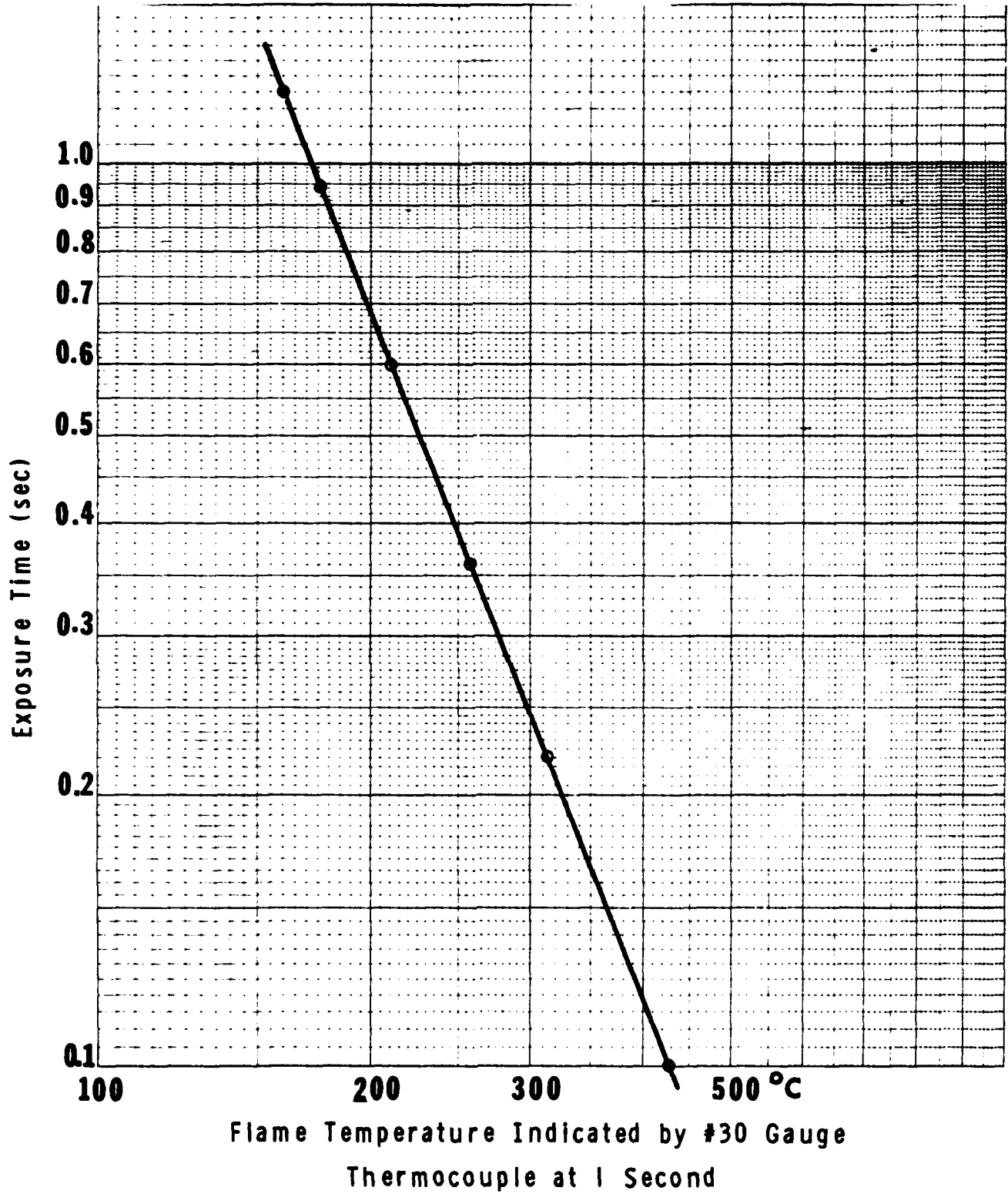


FIGURE 2

TABLE 1 - TIME-TEMPERATURE (°C) PROFILE AT BURN SITE												
Gauge	Seconds											
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	
40	147.8	257.8	224.2	209.2	203.4	216.2	211.0	211.5	218.5	206.3	208.0	
36	89.7	212.8	213.4	207.5	201.0	206.9	205.7	207.5	213.4	208.1	207.5	
30	39.5	119.2	143.3	157.6	161.5	168.4	174.0	178.6	187.9	190.3	194.3	
24	13.4	46.5	63.2	77.2	89.1	99.5	108.6	116.7	125.6	132.0	140.1	

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