

REPORT NO. NADC-80092-60

12



LEVEL

TELEMETRY SYSTEM FOR EVALUATION
OF BURN PROTECTION IN FULL-SCALE
FUEL FIRE MANIKIN EXPOSURES

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

1 May 1980

FINAL REPORT
AIRTASK NO. F61542001
Work Unit No. ZM503

DTIC
ELECTE
JUL 14 1980
S D

Approved for Public Release; Distribution Unlimited

Prepared for
NAVAL AIR SYSTEMS COMMAND
Department of the Navy
Washington, D.C. 20361

ADA086700

DC FILE COPY,

80 7 11 121

N O T I C E S

REPORT NUMBERING SYSTEM - The numbering of technical project reports issued by the Naval Air Development Center is arranged for specific identification purposes. Each number consists of the Center acronym, the calendar year in which the number was assigned, the sequence number of the report within the specific calendar year, and the official 2-digit correspondence code of the Command Office or the Functional Directorate responsible for the report. For example: Report No. NADC 78015-20 indicates the fifteenth Center report for the year 1978, and prepared by the Systems Directorate. The numerical codes are as follows:

CODE	OFFICE OR DIRECTORATE
00	Commander, Naval Air Development Center
01	Technical Director, Naval Air Development Center
02	Comptroller
10	Directorate Command Projects
20	Systems Directorate
30	Sensors & Avionics Technology Directorate
40	Communication & Navigation Technology Directorate
50	Software Computer Directorate
60	Aircraft & Crew Systems Technology Directorate
70	Planning Assessment Resources
80	Engineering Support Group

PRODUCT ENDORSEMENT - The discussion or instructions concerning commercial products herein do not constitute an endorsement by the Government nor do they convey or imply the license or right to use such products.

APPROVED BY: _____

E. J. Sturm

E. J. STURM
CLR USN

DATE: _____

6/16/80

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NADC-30092-60	2. GOVT ACCESSION NO. AD-A086700	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Telemetry System for Evaluation of Burn Protection in Full-Scale Fuel Fire Manikin Exposures.	5. TYPE OF REPORT & PERIOD COVERED Final rept.	
7. AUTHOR(s) J. R. Piergallini — A. M. Stoll	8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Aircraft and Crew Systems Directorate Naval Air Development Center Warminster, PA 18974	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Airtask No. F61542001 Work Unit No. ZM503	
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Systems Command Department of the Navy Washington, D. C. 20361	12. REPORT DATE 1 May 1980	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) ZF61542001	13. NUMBER OF PAGES 8	
15. SECURITY CLASS. (of this report) Unclassified		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for Public Release; Distribution Unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) 12 11		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Thermal injury Aviation Fuel Fires Protective Clothing		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An eighteen channel PAM/FM (Pulse Amplitude Modulated/Frequency Modulated) telemetry system was developed for measuring temperature rise on the surface of a manikin beneath protective clothing for full-scale fuel fire exposures in completely enveloping flames. Thermistors are used as temperature sensors at various locations on a manikin surface and backed by material of known thermal properties in order to correlate temperature rise with skin burn damage. The transmitted signals are recorded on analog magnetic tape		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

393532

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

and converted to a digital format for computer analysis.

The clothed manikin is passed through an Aviation Gasoline fire for three seconds (references 1 & 2) with the telemetry system recording data during this period. Temperatures are analyzed at 0, 1, 2 and 3-second intervals with voltage outputs from the thermistors being converted to resistance readings and temperature readings by equations developed from curves of thermistor characteristics.

Experimental results with respect to burn prediction are in agreement with data obtained by analysis of vesicant papers calibrated radiometrically to correlate with temperature-time effects productive of burns in living tissue. To date, 12 full-scale fuel fire tests have been conducted using the telemetry system and the performance of this system has exceeded original expectations in many respects such as sensitivity, accuracy and freedom from interference by ionizing gases within the flames (reference 3).

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

TABLE OF CONTENTS

	Page
INTRODUCTION	3
MATERIALS AND METHOD	4
RESULTS AND DISCUSSION	5
SUMMARY AND CONCLUSIONS	6
REFERENCES	6

LIST OF FIGURES

Title	Page
FIGURE 1 Distribution of Thinistors	7
FIGURE 2 Telemetry System	7

LIST OF TABLE

Title	Page
TABLE I Temperatures in °C	8

Accession For	
NTIS GRA&I	☒
DDC TAB	☐
Unannounced	☐
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or special
A	

INTRODUCTION

An eighteen-channel PAM/FM (Pulse Amplitude Modulated/Frequency Modulated) telemetry system was developed for measuring temperature rise on the surface of a manikin beneath protective clothing for full-scale fuel fire exposures in completely enveloping flames. The telemetry system within the manikin consists of transducers, low level commutator, oscillator, transmitter, battery pack and signal conditioning circuitry. The transmitted signals are received, demodulated and recorded on analog magnetic tape at a remote location. The transducer data can be viewed on an oscilloscope and transferred to an oscillographic record or a digital tape for computer analysis. Initially, 30 gauge copper-constantan thermocouples were installed on a manikin for temperature measurements at 18 locations. The manikin being constructed of different thicknesses of fiberglass and wood made it impractical to correlate the temperature measurements to human skin burns. A second approach was to install thermocouples on leather patches in order to correlate the rate of heating with that of human skin and compare results with the established procedure for prediction of skin burns in full-scale fuel fires; namely, analysis of vesicant papers at the same locations on the manikin surface under protective clothing. At this point it was decided that the sensitivity of the entire system needed upgrading because the full-scale input to the low level commutator was approximately 10 millivolts or 200°C. This meant that a more sensitive commutator was required, or amplification of each channel, or transducers with improved outputs. The latter was chosen as the most efficient direction to take because replacement of the low level commutator would require redesign of an already sensitive system, and amplification of each channel would require additional space within the manikin for stable low drift DC amplifiers operating over an extreme temperature range. The first thermistors chosen were epoxy-coated spheres 2.4 mm in diameter, weighing 0.0625 grams, and having a resistance of 3000 ohms at 25°C. It was immediately apparent that these thermistors did not exhibit adequate frequency response for short term fuel fire exposures of 3 seconds because of a maximum time constant of 10 seconds in still air. In the final configuration a thermistor called a Thinistor, manufactured by Victory Engineering Corporation (VECO), was chosen for its excellent frequency response and low resistance. It has a 0.3 to 0.4 second maximum time constant in still air and a resistance of 500 ohms at 25°C. The Thinistor, which is 3 mm square, 40 microns thick, and sintered to a 0.0254 mm nickel foil, is mounted on a leather patch for burn injury assessments.

MATERIALS AND METHOD

The manikin is instrumented with 18 thermistors (VECO Thinistors) as illustrated in Figure 1. A schematic of the telemetry and associated electrical equipment is shown in Figure 2. The manikin chest cavity contains the transducer circuitry and battery, commutator, oscillator, and transmitter. The antenna is mounted above the neck in place of the head and a 28 volt battery pack is mounted in the lower trunk. The Thinistors are glued with a thin film of Duco cement on leather patches so that the temperature data can be correlated with skin burn assessments at locations illustrated in Figure 1. The receiver, discriminator, amplifier, oscilloscope and analog magnetic tape unit are located in a panel truck or table outside the fuel fire pit enclosure. The oscilloscope is used to monitor the data during and after an exposure by visual inspection of each channel's displacement. The crane position indicator places a signal on analog magnetic tape corresponding to four physical locations of the manikin within the fire at 0, 1, 2, and 3 seconds' exposure. The procedure before conducting the telemetry portion of each experiment consists of measuring the excitation voltage across the transducers and shorting out and recording each Thinistor output on analog magnetic tape. After a run is completed, two types of data analysis can be performed. One system transfers the analog magnetic tape output to an oscillographic record for analysis. The displacement of each channel can be measured at selected intervals and the corresponding millivolt output established. Readings can be analyzed for any time or any increment during the period that the magnetic tape recorder is operating either before, during or after a fuel fire exposure. The second system automatically analyzes the analog magnetic tape output by computer conversion into a digital format for computer analysis. Each system generates data which correspond to millivolts of output for each Thinistor at specific intervals. This is accomplished by measuring the displacement between zero output and the peak output of the Thinistors. Knowing the corresponding millivolt output required to generate this displacement, the millivolt output of each channel can be determined as described by equation 2. Having the millivolt output of each Thinistor at the specified interval, a computer program converts the data to resistance readings by using equation 4 and then to temperature readings by using equations 5 through 10, which describe curve No. 2 in VECO Product Bulletin MVM 1994A, a semilogarithmic plot of Resistance Ratio, $R(T)/R(25^{\circ}\text{C})$ vs. Temperature $^{\circ}\text{C}$. The 150°C point on the VECO curve is obtained by extrapolation. A 10 millivolt signal corresponds to a temperature of 22.66°C and a 1 millivolt signal to 95.88°C .

$$\frac{12.6 \text{ millivolts}}{Y \text{ cm}} = \frac{V_T \text{ millivolts}}{Z \text{ cm}} \quad \text{Eq. (1)}$$

$$V_T = \frac{12.6 Z}{Y} \quad \text{Eq. (2)}$$

- 12.6 = Full-scale input, peak reference
 V_T = Voltage drop across Thinistor, R_T
 Y = Displacement between zero reference and peak reference
 Z = Displacement between Thinistor output and zero reference
 $V_S = I(R_F + R_T)$ and $I = V_T/R_T$ Eq. (3)
 $R_T = \frac{V_{TRF}}{V_S - V_T}$ Eq. (4)
 V_S = Voltage across R_F and $R_T = .2843$ volts
 R_F = Resistor in series with Thinistor = 9000 ohms
 R_T = Thinistor Resistance
 $^{\circ}C = \frac{7.28619 - \text{Loge } R_T}{.04286}$ $0^{\circ}C$ to $25^{\circ}C$ Eq. (5)
 1460 ohms to 500 ohms
 $^{\circ}C = \frac{7.11836 - \text{Loge } R_T}{.03615}$ $25^{\circ}C$ to $50^{\circ}C$ Eq. (6)
 500 ohms to 202.5 ohms
 $^{\circ}C = \frac{6.86174 - \text{Loge } R_T}{.03102}$ $50^{\circ}C$ to $75^{\circ}C$ Eq. (7)
 202.5 ohms to 93.25 ohms
 $^{\circ}C = \frac{6.60678 - \text{Loge } R_T}{.02762}$ $75^{\circ}C$ to $100^{\circ}C$ Eq. (8)
 93.25 ohms to 46.75 ohms
 $^{\circ}C = \frac{6.15381 - \text{Loge } R_T}{.02309}$ $100^{\circ}C$ to $125^{\circ}C$ Eq. (9)
 46.75 ohms to 26.25 ohms
 $^{\circ}C = \frac{5.87017 - \text{Loge } R_T}{.02082}$ $125^{\circ}C$ to $150^{\circ}C$ Eq. (10)
 26.25 ohms to 15.60 ohms

RESULTS AND DISCUSSION

Table I shows the Reference Temperatures, which are the Thinistor Temperatures before an exposure, and the changes in temperature as the manikin goes through the fuel fire. An additional refinement incorporated in the computer program, but not described in this paper, corrects the Thinistor Reference Temperatures to ambient by measuring each Thinistor resistance, calculating the corresponding temperature, and algebraically adding the difference between ambient and the calculated temperature to the Reference Temperature. Table I was generated by a computer digitizing the analog magnetic tape and providing voltage readings for Thinistor outputs. These voltages are converted to resistances using Equations 2 and 4 and then to temperatures using Equations 5 through 10. It is not within the scope of this paper to interpret the data in Table I, but it can be stated that the most severely burned area in this fuel fire would be the left leg, keeping in mind that leather heats at a rate three times that of human skin, and that for a three-second exposure, a temperature change of approximately $76^{\circ}C$ from an initial temperature of $32.5^{\circ}C$ must be reached before a severe burn is indicated. As a check of the telemetry system, a 108.14 ohm resistor was placed in channel 16. The telemetry system measured this resistance as 107.12 ohms corresponding to a temperature accuracy of $0.31^{\circ}C$, which is typical of the accuracy and sensitivity necessary for making human skin burn protection evaluations.

SUMMARY AND CONCLUSIONS

Experimental results with respect to burn prediction are in agreement with data obtained by analysis of temperature-sensitive vesicant papers calibrated radiometrically to correlate with temperature-time affects productive of burns in living tissue. To date, 12 full-scale fuel fire tests have been conducted using the telemetry system, and the performance of this system has exceeded original expectations in many respects, such as sensitivity, accuracy, and freedom from interference by ionizing gases within the flames.

REFERENCES

1. Stoll, A. M., L. R. Munroe, M. A. Chianta, J. R. Piergallini and D. E. Zaccaria. A Facility and Method for Evaluation of Thermal Protection. NADC-75286--40 of 1 Dec 1975. Aviation, Space and Environmental Medicine. 47(11): 1177-1181 Nov 1976.
2. Piergallini, J. R. Design Concept for Fuel Fire Facility Scale-Down. NADC-79227-60 of 20 Aug 1979.
3. Stoll, A. M., L. R. Munroe, J. R. Piergallini and M. A. Chianta. Telemetry System for Burn Injury Assessment. NADC-CS-7115 of 10 Sep 1971.

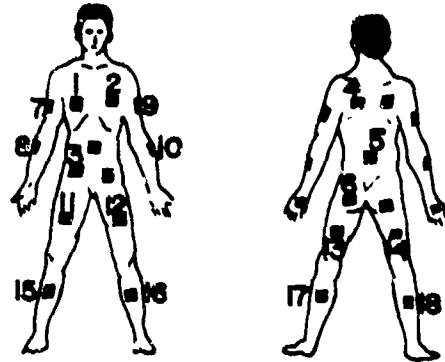
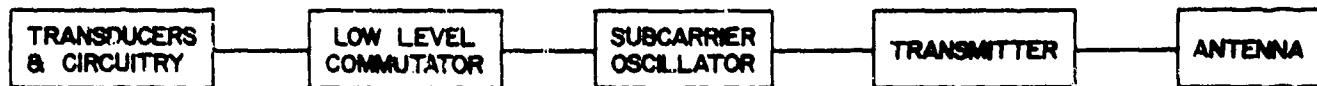


FIGURE 1. DISTRIBUTION OF THINISTORS

MANIKIN



REMOTE LOCATION

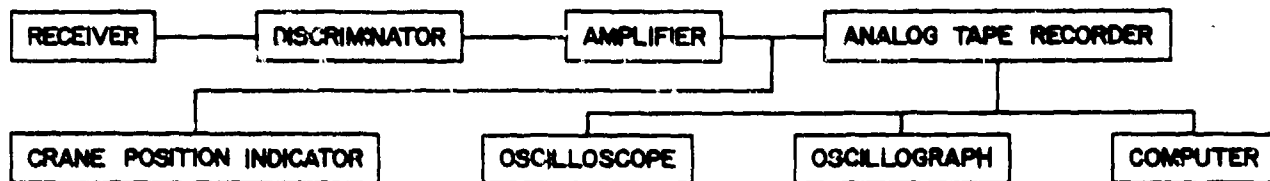


FIGURE 2. TELEMETRY SYSTEM

TABLE I - TEMPERATURES IN °C

TABLE I - TEMPERATURES IN °C					
		Change in Temperature from Reference			
Channel	Reference	0 second	1 second	2 second	3 second
1	31.92	1.86	4.76	14.97	15.54
2	31.52	1.76	2.61	0.94	2.41
3	25.81	1.52	4.44	9.48	12.30
4	34.57	-0.18	0.81	4.78	22.64
5	35.69	1.31	0.77	6.66	24.44
6	33.55	-1.26	1.18	14.88	36.46
7	35.45	1.20	1.96	10.66	7.54
8	36.43	1.99	8.79	20.25	12.56
9	39.89	1.79	3.03	8.71	8.24
10	34.08	2.94	14.55	28.05	24.28
11	39.26	3.75	11.12	15.22	11.37
12	42.78	6.91	25.82	42.62	54.60
13	36.30	1.57	7.70	33.08	68.52
14	36.25	0.71	6.84	22.99	21.91
15	37.92	5.39	15.03	21.96	30.73
16	* 70.53				
17	33.75	1.05	13.23	60.44	94.42
18	36.22	1.89	15.28	71.06	74.21
*Resistor for assessing accuracy of system					

D I S T R I B U T I O N L I S T

REPORT NO. NADC-80092-60

AIRTASK NO. F61542001

Work Unit No. ZM503

	<u>No. of Copies</u>
DDC	12
NAVAIRSYSCOM (AIR-950D)	5
(2 for retention)	
(1 for AIR-340)	
(1 for AIR-531)	
(1 for AIR-5311E)	