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Report SAM-TR-78-33

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FIGHTER INDEX OF THERMAL STRESS: RELATION
TO WEATHER CONDITIONS AT ATC AND TAC BASES.

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Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235



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This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Fighter Index of Thermal Stress (FITS) is a tool recently developed for minimizing hazardous aircrew heat stress during hot-weather operations. The FITS table, entered with ground dry bulb temperature (T_{db}) and dewpoint temperature (T_{dp}), yields a numerical estimate of cockpit heat stress. Superimposed on the table are Normal, Caution, and Danger Zones, with footnotes recommending appropriate precautions. This report examines the relationship of FITS to typical weather conditions at 30 ATC and TAC bases in the continental United States. An appendix presents a graph for each base, indicating the frequency of readings in the Caution and Danger Zones for each hour of the day and month of the year.		

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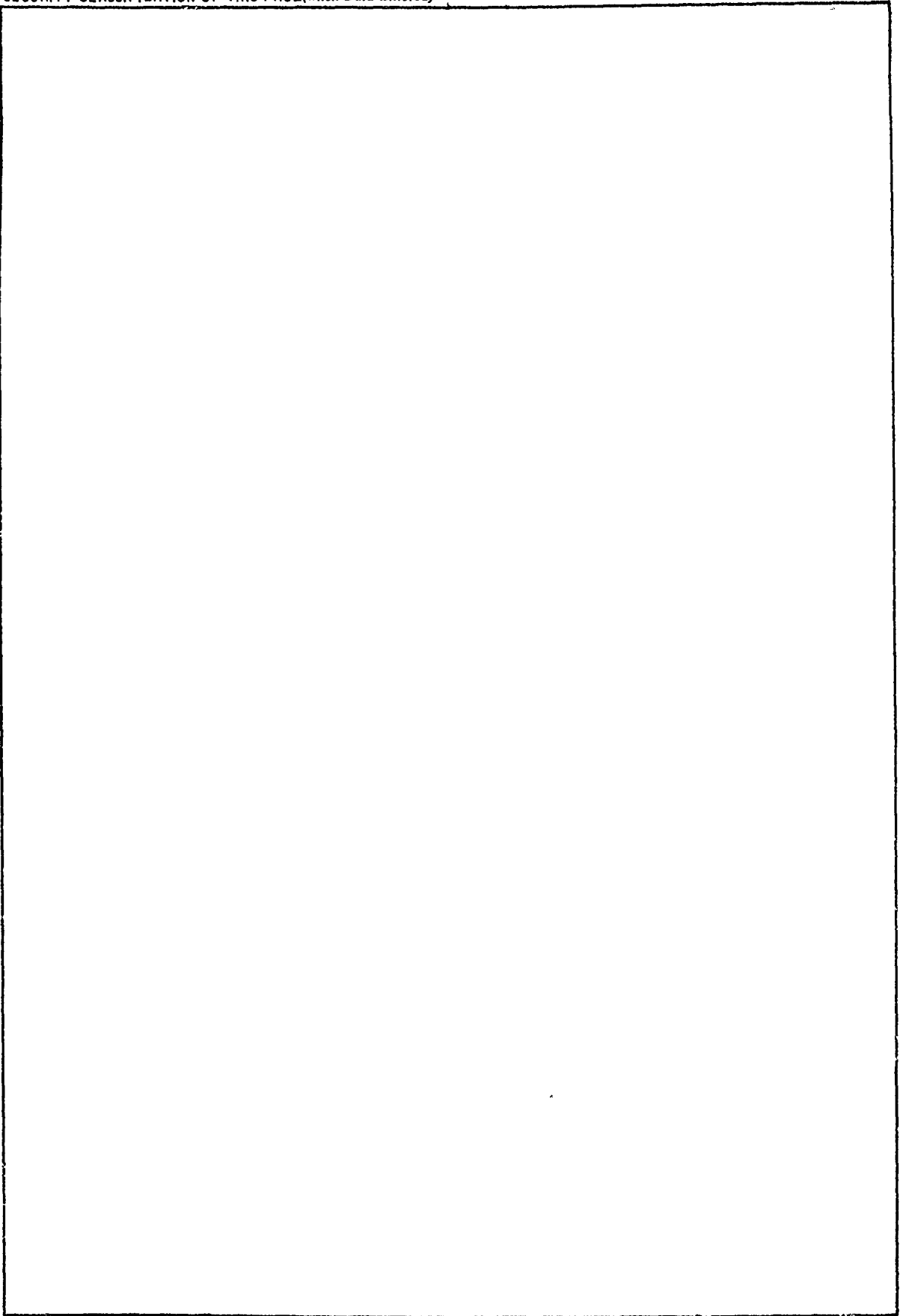
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FIGHTER INDEX OF THERMAL STRESS:
RELATION TO WEATHER CONDITIONS
AT ATC AND TAC BASES

INTRODUCTION

The Fighter Index of Thermal Stress (FITS) was developed to assist USAF commanders in minimizing the adverse effects of heat stress on aircrews during hot-weather flight operations. The mathematical derivation of FITS and the rationale for setting exposure limits appear in detail elsewhere (2). This report briefly describes the FITS concept, then presents data relating it to weather conditions at selected USAF bases.

DERIVATION OF TABLES

FITS was developed from the widely accepted Wet Bulb Globe Temperature (WBGT) (3), which yields a single value representing effective heat stress based on three weighted variables: air temperature, humidity, and radiant heating. Recent measurements of cockpit conditions show that during low-level flight (< 3000 ft, or 915 m, AGL), cockpit WBGT is directly related to ground WBGT (1). Several simplifying assumptions were made (2) to produce the following equation describing thermal conditions for cockpits of one- and two-place jet aircraft during low-level flight:

$$\text{FITS} = .83 T_{\text{pwb}} + .36 T_{\text{db}} + 5.04^{\circ}\text{C}$$

where T_{pwb} = psychrometric wet bulb temperature and T_{db} = dry bulb temperature, both measured at ground level and expressed in $^{\circ}\text{C}$. Psychrometric equations were used to produce FITS in table form (Tables 1A and 1B). The notes which appear at the bottom of both tables are an integral part of the concept.

Selection of exposure limits (Caution and Danger Zones) was a complex problem. Factors considered include aircrew age, physical fitness, heat acclimatization, clothing, and metabolic rate (2). The Caution Zone ($32^{\circ}\text{C} \leq \text{FITS} < 38^{\circ}\text{C}$) includes conditions that should be physiologically compensable when adequate hydration is maintained. The Danger Zone ($\text{FITS} \geq 38^{\circ}\text{C}$) produces progressive heat storage, with adverse effects on performance and on tolerance for other stresses such as acceleration and hypoxia.

TABLE 1A. FIGHTER INDEX OF THERMAL STRESS IN °C (LOW-LEVEL FLIGHT, CLEAR SKY TO LIGHT OVERCAST)

Instructions: Enter with local dry bulb temperature and dewpoint temperature; at intersection read FITS value and zone. Applies only to lightweight flight clothing. See notes for zone explanation. The X denotes combinations above saturation temperature.

Dry Bulb Temp. (°C)	Zone	Dewpoint Temperature (°C)									
		≤0	5	10	15	20	25	30	35	40	≥45
20.0	Normal	21	22	24	26	29	X	X	X	X	X
22.5		23	24	26	28	30	X	X	X	X	X
25.0		24	26	27	29	31	35	X	X	X	X
27.5		26	27	29	31	33	36	X	X	X	X
30.0		28	29	31	32	35	37	41	X	X	X
32.5		29	31	32	34	36	39	42	X	X	X
35.0	Caution ¹	31	32	34	36	37	40	43	46	X	X
37.5		33	34	35	37	39	42	45	48*	X	X
40.0		34	35	37	39	41	43	46	49*	52	X
42.5		36	37	38	40	42	44	47*	50	54	X
45.0	Danger ²	37	39	40	41	43	46	48*	52	55	58
47.5		39	40	41	43	45	47*	50	53	56	59
50.0		41	42	43	44	46	48*	51	54	57	61

¹Caution Zone: (1) Be aware of heat stress.
(2) Limit ground period (preflight and ground standby) to 90 min.
(3) Minimum 2-hr recovery between flights.

²Danger Zone: (1) Cancel low-level flights (below 915 m AGL).
(2) Limit ground period to 45 min.
(3) Minimum 2-hr recovery between flights.

*When value is greater than 46, cancel all nonessential flights.

Comments:

Observe the following general hot-weather precautions: (1) Allow time for acclimatization to hot weather; avoid extreme efforts on the first several days of exposure. (2) Try to drink more water than thirst dictates; water intake is vital to sweat secretion, the body's main defense against heat.

This table is not to be used when CD, immersion, or arctic flight equipment is worn.

TABLE 1B. FIGHTER INDEX OF THERMAL STRESS IN °F (LOW-LEVEL FLIGHT, CLEAR SKY TO LIGHT OVERCAST)

Instructions: Enter with local dry bulb temperature and dewpoint temperature; at intersection read FITS value and zone. Applies only to lightweight flight clothing. See notes for zone explanation. The X denotes combinations above saturation temperature.

Dry Bulb Temp. (°F)	Zone	Dewpoint Temperature (°F)								
		≤30	40	50	60	70	80	90	100	≥110
70	Normal	70	73	76	81	86	X	X	X	X
75		74	77	80	84	89	X	X	X	X
80		77	80	83	87	92	98	X	X	X
85		81	83	86	90	95	101	X	X	X
90		84	87	90	93	98	104	110	X	X
95	Caution ¹	88	90	93	96	101	108	112	X	X
100		91	93	96	99	104	109	115	122*	X
105		94	96	99	102	107	112	118*	124	X
110		97	99	102	105	109	114	120*	126	133
115	Danger ²	100	102	105	109	112	117*	123	129	136
120		104	105	108	111	115	120*	125	131	138

¹Caution Zone: (1) Be aware of heat stress.
(2) Limit ground period (preflight and ground standby) to 90 min.
(3) Minimum 2-hr recovery between flights.

²Danger Zone: (1) Cancel low-level flights (below 3,000 ft AGL).
(2) Limit ground period to 45 min.
(3) Minimum 2-hr recovery between flights.

*When value is greater than 115, cancel all nonessential flights.

Comments:

Observe the following general hot-weather precautions: (1) Allow time for acclimatization to hot weather; avoid extreme efforts on the first several days of exposure. (2) Try to drink more water than thirst dictates; water intake is vital to sweat secretion, the body's main defense against heat.

This table is not to be used when CD, immersion, or arctic flight equipment is worn.

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WEATHER DATA

FITS was designed for the types of aircraft flown primarily by the Air Training Command (ATC) and the Tactical Air Command (TAC). To assess the impact of FITS guidelines on USAF flying operations, weather data were examined for the 30 ATC and TAC flying bases located in the continental United States. Hourly T_{db} and T_{wb} records for a 6- to 12-year period were used to determine for each base the percentage of FITS readings falling in the Caution and Danger Zones for each hour of the day and month of the year.

Results are summarized in Table 2, and detailed data for each base appear in Appendix A. FITS applies only to the hours between local sunrise and sunset, since the index assumes the contribution of radiant heat due to sunlight.

DISCUSSION AND CONCLUSION

The majority of ATC and TAC bases are located in the southern United States. At many of these bases on summer days, Caution readings are the rule, with a significant number of hours in the Danger Zone. Taking Bergstrom AFB as an example, planners there can expect Caution conditions during most daylight hours from May through September, with Danger readings commonly occurring between noon and sunset, June through September.

This information can be used in briefing all operations and flying personnel on the problems and hazards of heat stress, together with proper preventive measures. Schedules can be planned to avoid low-level flights and repeat missions by the same persons during the hottest weather.

It is recommended that each base set up a hot-weather alert system similar to that used for windchill at northern bases during the winter months. The Operations Office would then monitor weather forecasts to predict conditions in the FITS Caution and Danger Zones. Local temperature and humidity readings would also be followed in real time so that operations could be modified to prevent undue heat stress or to take advantage of unexpectedly cool conditions. The FITS chart should be posted in all flight-planning areas, with supervisory personnel responsible for enforcement of preventive measures.

In conclusion, FITS is designed as an aid to USAF personnel in planning and carrying out low-level fighter/trainer missions in hot weather, while minimizing the heat-stress effects which are often subtle but are nevertheless real. A study of USAF data shows that accident rates for fighter aircraft peak in summer, when heat may be a contributing factor (4). Data presented here should help to ameliorate any such effect.

TABLE 2. FITS WEATHER-DATA SUMMARY FOR 30 ATC AND TAC BASES

Base	Data years First - Last	No. of months*		
		C5	D1	D5
Bergstrom AFB TX	1966-75	7	4	2
Cannon AFB NM	1966-75	3	0	0
Chanute AFB IL	1951-60	4	3	0
Columbus AFB MS	1966-76	5	3	1
Craig AFB AL	1966-75	7	4	2
Davis-Monthan AFB AZ	1966-75	4	0	0
Eglin AFB FL	1966-75	6	4	2
England AFB LA	1966-75	7	4	2
George AFB CA	1966-76	4	0	0
Holloman AFB NM	1966-75	3	0	0
Homestead AFB FL	1966-75	12	3	0
Keesler AFB MS	1955-64	7	4	2
Langley AFB VA	1966-76	4	3	0
Laughlin AFB TX	1954-62	7	4	1
Lowry AFB CO	1966-75	0	0	0
Luke AFB AZ	1966-75	5	4	2
MacDill AFB FL	1966-76	9	4	2
Mather AFB CA	1966-76	5	0	0
Moody AFB GA	1966-75	7	3	0
Mountain Home AFB ID	1966-76	2	0	0
Myrtle Beach AFB SC	1966-76	6	4	2
Nellis AFB NV	1970-76	4	3	0
Randolph AFB TX	1970-76	7	4	0
Reese AFB TX	1950-60	4	0	0
Seymour Johnson AFB NC	1966-76	5	3	1
Shaw AFB SC	1966-76	5	3	1
Sheppard AFB TX	1970-76	6	4	3
Vance AFB OK	1966-76	5	3	0
Webb AFB TX	1966-75	5	0	0
Williams AFB AZ	1966-76	5	3	0

*Number of months having > 5 days in Caution Zone (C5), > 1 day in Danger Zone (D1), and > 5 days in Danger Zone (D5).

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2. Stribley, R. F., and S. A. Nunneley. Fighter index of thermal stress: Development of interim guidance for hot-weather USAF operations. SAM-TR-78-6, Feb 1978.
3. Yaglou, C. P., and D. Minard. Control of heat casualties at military training centers. *Arch Ind Health* 16:302-316 (1957).
4. Zeller, A. F. Curves in your future. USAF Inspection and Safety Center, USAF Safety Officer's Study Kit, pp. 7-13, Nov 1972.

APPENDIX A

Graphs show frequency of FITS Caution and Danger Zone weather conditions at the following 30 USAF bases:

<u>BASE NAME</u>	<u>STATE</u>
Bergstrom	Texas
Cannon	New Mexico
Chanute	Illinois
Columbus	Mississippi
Craig	Alabama
Davis-Monthan	Arizona
Eglin	Florida
England	Louisiana
George	California
Holloman	New Mexico
Homestead	Florida
Keesler	Mississippi
Langley	Virginia
Laughlin	Texas
Lowry	Colorado
Luke	Arizona
MacDill	Florida
Mather	California
Moody	Georgia
Mountain Home	Idaho
Myrtle Beach	South Carolina
Nellis	Nevada
Randolph	Texas
Reese	Texas
Seymour Johnson	North Carolina
Shaw	South Carolina
Sheppard	Texas
Vance	Oklahoma
Webb	Texas
Williams	Arizona

CANNON AFB NM

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

T I N F

H H 2 F

J E M A N J J A S O N D

III:ION

FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE CONDITIONS F² TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: . > 5 DAYS/MONTH IN CAUTION ZONE
0 > 1 DAY / MONTH IN DANGER ZONE
Ø > 5 DAYS/MONTH IN DANGER ZONE

COLUMBUS AB MS

TIME

J F M A M J J A S O N D

IL TIPO

FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE
CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: . > 5 DAYS/MONTH IN CAUTION ZONE
 0 > 1 DAY / MONTH IN DANGER ZONE
 Ø > 5 DAYS/MONTH IN DANGER ZONE

TIME.

III 25

DAVIS--MONTAN AFB AZ

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

III 24

J F M A M J J A S O N D

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J F M A M J J A S O N D

II. THEOREM

FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE
CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: . > 5 DAYS/MONTH IN CAUTION ZONE
 O > 1 DAY / MONTH IN DANGER ZONE
 Ø > 5 DAYS/MONTH IN DANGER ZONE

ENGLAND AFB LA

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J F N A N J J A S O N D
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FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE
CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: • > 5 DAYS/MONTH IN CAUTION ZONE
0 > 1 DAY / MONTH IN DANGER ZONE
Ø > 5 DAYS/MONTH IN DANGER ZONE

FOLLOMAN AFB mi

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FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE
CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: • > 5 DAYS/MONTH IN CAUTION ZONE
 0 > 1 DAY /MONTH IN DANGER ZONE
 Ø > 5 DAYS/MONTH IN DANGER ZONE

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A 3x7 grid of dots representing a 3x7 matrix. The dots are arranged in three rows and seven columns.

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VEESLER AFB MS

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

TIME

J F M A M J J A S O N D

MONTH

HOMESTEAD AFB FL

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

TIME

J F M A M J J A S O N D

MONTH

FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE
CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: . > 5 DAYS/MONTH IN CAUTION ZONE
0 > 1 DAY/MONTH IN DANGER ZONE
Ø > 5 DAYS/MONTH IN DANGER ZONE

LAUGHLIN AFB TX

C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
TIME																								

A 4x10 grid of dots. The dots are arranged in four rows and ten columns. The following positions (row, column) contain the letter 'C': (1, 6), (1, 7), (1, 8), (1, 9), (2, 6), (2, 7), (2, 8), (2, 9), (3, 6), (3, 7), (3, 8), (3, 9), (4, 6), (4, 7), (4, 8), (4, 9). All other positions contain a single dot.

J F H A M J J A S O N D

“MONTY”

FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE
CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: . > 5 DAYS/MONTH IN CAUTION ZONE
 0 > 1 DAY /MONTH IN DANGER ZONE
 Ø > 5 DAYS/MONTH IN DANGER ZONE

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MONTH

MACDILL AFB FL

[illegible]

J F N A M J J A S O N D

II. NOISE

FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: . > 5 DAYS/MONTH IN CAUTION ZONE
0 > 1 DAY / MONTH IN DANGER ZONE
Ø > 5 DAYS/MONTH IN DANGER ZONE

MOODY AFB GA	MOUNTAIN HOME AFB ID
0	0
1	1
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3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23
J F M A M J J A S O N D	J F M A M J J A S O N D

T I M E

MONTH

FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE
CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: > 5 DAYS/MONTH IN CAUTION ZONE
0 > 1 DAY / MONTH IN DANGER ZONE
Ø > 5 DAYS/MONTH IN DANGER ZONE

NELLIS AFB NV

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MYRTLE BEACH AFB SC

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MONTH

FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE
CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: • > 5 DAYS/MONTH IN CAUTION ZONE
0 > 1 DAY/MONTH IN DANGER ZONE
Ø > 5 DAYS/MONTH IN DANGER ZONE

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J F M A M J J A S O N D												J F M A M J J A S O N D											
MONTH												MONTH											

FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE
CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: • > 5 DAYS/MONTH IN CAUTION ZONE
0 > 1 DAY / MONTH IN DANGER ZONE
Ø > 5 DAYS/MONTH IN DANGER ZONE

SEYMOUR JOHNSON AFB NC												SHAW AFB SC											
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FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE
CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: . > 5 DAYS/MONTH IN CAUTION ZONE
0 > 1 DAY/MONTH IN DANGER ZONE
Ø > 5 DAYS/MONTH IN DANGER ZONE

WILLIAMS AFB, AZ

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TIME

A 5x10 grid of dots. The dots are arranged in a pattern that resembles a stylized letter 'C' or a similar shape. The dots are black and the background is white.

J F M A M J J A S O N D

MONTH:

FIGHTER INDEX OF THERMAL STRESS (FITS): AVERAGE CONDITIONS BY TIME OF DAY (LOCAL STD) AND MONTH OF YEAR.

KEY: .> 5 DAYS/MONTH IN CAUTION ZONE
0> 1 DAY /MONTH IN DANGER ZONE
Ø> 5 DAYS/MONTH IN DANGER ZONE