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FIGHTER INDEX OF THERMAL STRESS: DEVELOPMENT OF INTERIM GUIDANCE FOR HOT-WEATHER USAF OPERATIONS

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USAF SCHOOL OF AEROSPACE MEDICINE
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Operation of fighter and trainer aircraft in hot climates can impose significant heat strain on aircrew members. Until now, commanders have lacked practical guidance for aircrew thermal protection. A primary obstacle has been the paucity of data relating cockpit conditions to ground weather, but that gap is now being filled. A review of existing heat-stress indices revealed that none of them met the criteria for operational practicality. The Wet Bulb Globe Temperature (WBGT) Index was selected as a starting point because of the large data base already

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available. A new scheme was then developed, the Fighter Index of Thermal Stress (FITS), which uses recently acquired cockpit data to generate predictive equations. The final product is a single table from which base personnel, using only conventional weather data (ambient air temperature and relative humidity), can read FITS values. Normal, Caution, and Danger zones are designated on the chart, based upon estimates of aircrew physiological status and the need to avoid significant performance decrements. Appropriate protection procedures are recommended for each zone.

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FIGHTER INDEX OF THERMAL STRESS: DEVELOPMENT OF INTERIM GUIDANCE FOR HOT-WEATHER USAF OPERATIONS

INTRODUCTION

Aircrew heat stress is a persistent problem in high-performance aircraft operating in hot climates, especially during ground standby (10) and low-level flight (3). Contributing factors include high ambient air temperatures, humidity, sunlight, and the limited size of on-board air-conditioning units (20, 21). The problem is a source of concern because heat stress can impair human mental performance (7, 22, 29) and also lower tolerance for other physiological stresses of high-performance flight (1).

Until now, USAF commanders have lacked practical guidance for protecting aircrews from hazardous thermal strain, although some bases in the Southern United States have adopted local criteria for stopping low-level training flights or exercises in extremely hot weather. The limiting factor in development of general guidelines has been the paucity of information relating ground weather to cockpit thermal conditions; however, recent advances now make it possible to predict cockpit conditions during low-level flight.

The following characteristics are indispensable for a practical index: (1) inputs should be routine weather data, (2) the index should be easy to read, (3) it should be presented on a single page, and (4) it should be clearly related to operational go/no-go decisions. This report describes the development of such a scheme, the Fighter Index of Thermal Stress (FITS).

DERIVATION

Selection of the Basic Heat-Stress Scheme

Many heat-stress schemes and indices exist in the literature (23). Some are clearly inappropriate for use in the flying environment, and others were eliminated as too complex for aircrew use. Three indices were seriously considered as a basis for the FITS.

1. Effective Temperature (ET) (13). This index is simple to use and widely accepted, but it was primarily developed from subjective

evaluation of nonradiant environments and was validated for near-comfort conditions rather than extremes. Also, equal ETs have been shown at times to represent unequal physiological stress.

2. Heat Stress Index (HSI) (5, 17). The HSI has a sound physiological basis, expressing stress as the ratio between required sweat evaporation and the maximum possible in a given environment. Unfortunately, the scheme uses ten steps and several graphs to determine stress level.

3. Wet Bulb Globe Temperature (WBGT) (19, 30). This index was empirically developed to minimize heat casualties among military recruits. As well as being used for the military, it is the principal scheme recommended for evaluating industrial heat stress by government agencies: Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health (NIOSH), and American Conference of Governmental Industrial Hygienists (ACGIH). It does not require knowledge of wind velocity and is an algebraic equation using dry bulb temperature (T_{db}), large (150 mm) black globe temperature (T_{bgl}), and natural wet bulb temperature (T_{wb}), as shown in equation 1:

$$WBGT = .7\ T_{wb} + .2\ T_{bgl} + .1\ T_{db} \qquad (1)$$

Although the equation is simple, T_{bgl} is not normally reported by weather stations.

None of these schemes satisfactorily meets all four required characteristics listed in the introduction. A nomograph or table would fulfill the requirement of single-page presentation; however, a nomograph requires additional instruction and interpretation in its use. The most practical index appears to be one that relates cockpit and ground conditions by using not more than two entry variables. The problem thus becomes one of selecting a suitable index and developing a new scheme or road map to obtain an approximation to this index. A modification of WBGT was used to produce the Fighter Index of Thermal Stress.

Development of the Fighter Index of Thermal Stress

WBGT was selected as the starting point for two important reasons: (1) the considerable amount of recent work relating WBGT to physiological tolerance limits and human performance (12); and (2) a growing WBGT data base from recordings of cockpit conditions during fighter sorties.

Two special instruments, the Miniature Environmental Monitor (MEM) developed at the USAF School of Aerospace Medicine (14) and the Thermal Data Recording System (TDRS) of the RAF Institute of Aviation Medicine (2), are being used to record cockpit environmental conditions. Each measures four aspects of the thermal environment: T_{db}, T_{bgs} (small, 50 mm, globe), T_{wb} or dewpoint, and air velocity (V). Data are now available for a variety of fighter aircraft including the A-7 and F-15 (unpublished USAFSAM data); A-10 (28); and F-4, Buccaneer, and Harrier (3). From this information, broad generalizations can be made for estimating globe temperatures and relating cockpit conditions to local weather.

Environmental data collected by the MEM and TDRS show that the small black globe temperature in the cockpit exceeds the dry bulb temperature by an average of $4^{\circ}C$ in moderate overcast (MO) with shadows visible, and by about $10^{\circ}C$ in direct sunlight (DS). Therefore:

Direct sun $T_{bgs} = T_{db} + 10^{\circ}C$ (2)

Moderate overcast $T_{bgs} = T_{db} + 4^{\circ}C$ (3)

A conversion is required for valid comparison of WBGT based upon T_{bgs} to the literature, which uses T_{bgl}. Recent work by Harrison et al. (11) showed that aircraft cockpit WBGTs are related as shown:

$$WBGT_{bgl} - WBGT_{bgs} = .12\ (T_{bgs} - T_{db}) \quad (4)$$

where $WBGT_{bgl}$ uses large globe and $WBGT_{bgs}$ uses small globe. Substituting equations 2 and 3 into equation 4 yields:

Direct sun $WBGT_{bgl} - WBGT_{bgs} = 1.2^{\circ}C$ (5)

Moderate overcast $WBGT_{bgl} - WBGT_{bgs} = .48^{\circ}C$ (6)

Until recently there was little information relating standby conditions and low-level flight to ambient WBGT. A predictable relationship does exist, however, as shown by the work of Harrison et al. (11). Data were obtained from a total of 32 flights aboard Harrier, Phantom, and Buccaneer aircraft during the summers of 1974 and 1975 in Germany (3). Values for the WBGT were averaged for each flight and correlated with mean ground WBGT. Based upon their data ($r=0.83$, $n=14$, $p<.001$), the following relationship was observed for flights below 915 m (3,000 ft) above ground level (AGL):

$$WBGT_{bgs\ (ground)} = (WBGT_{bgs\ (cockpit)} - .333)/1.183 \quad (7)$$

where $WBGT_{bgs\ (cockpit)}$ is computed using a psychrometric T_{wb}, and $WBGT_{bgs\ (ground)}$, a naturally convected T_{wb}. A review of data for the F-4 (3), A-10 (28), A-7, and F-15 (USAFSAM unpublished data) shows that bubble-canopy fighter aircraft generally follow this relationship.

Harrison et al. have shown that for air velocities up to 3 m/s, the large globe and small globe temperatures are related as shown below:

$$T_{bgs} = .71\ T_{bgl} + .29\ T_{db} \quad (8)$$

Additionally, a large black globe exposed to ground ambient conditions is approximately 10°C higher than ground T_{db} for the direct-sun condition and 4°C higher than ground T_{db} for the moderate-overcast condition, the larger globe size being compensated for by a higher air velocity (3, 12). For a T_{bgl} and T_{db} difference of 10°C and most ambient air velocities, the naturally convected wet bulb temperature is 2.2°C higher than the psychrometric wet bulb temperature (12). Similarly, when t_{bgl} and T_{db} differ by 4°C, the naturally convected wet bulb temperature is approximately .9°C higher than the psychrometric wet bulb temperature.

Combining equations 1, 5, 6, 7, and 8, and using the assumptions given above, yields the following set of equations that relate cockpit environment to ambient conditions:

$$FITS_{DS} = .8281\ T_{pwb} + .3549\ T_{db} + 5.08^{\circ}C \qquad (9)$$

$$FITS_{MO} = .8281\ T_{pwb} + .3549\ T_{db} + 2.23^{\circ}C \qquad (10)$$

where T_{pwb} and T_{db} are ground psychrometric wet bulb and dry bulb temperatures, respectively. Equations 9 and 10 are the FITS computational equations for estimating WBGT in the cockpit of fighter aircraft and are based upon readily available information. The FITS value obtained can be directly related to the cockpit WBGT value and its physiological interpretations.

Selection of Stress Limits

Typically, WBGT is used to set exposure limits for men at work in hot environments, but the Threshold Limit Values (TLVs) used by NIOSH and military training groups cannot be directly applied to aircrews because of different exposure conditions. Table 1 lists the sequence of environments normally encountered by an aircrew, together with typical duration of exposure to each. Preflight inspection constitutes light work (150 kcal/hr) (12), and in-flight crew metabolic rates average 100-225 kcal/hr (24). Summer clothing and equipment (e.g., helmet and parachute harness) provide 1.5- to 2.0-clo insulation (8, 18).

For work in this light-to-moderate range, multiple studies show that a core (rectal) temperature of 38°C is the upper limit desirable. Above this temperature, performance can be impaired (4, 7), acceleration tolerance diminishes (1), and human thermoregulation becomes inefficient (16). In fact, as deep-body temperature exceeds 38°C, an increasing number of persons approach collapse; and at 39°C, about 50% of subjects are incapacitated (16).

The core temperature of men doing moderate work and wearing light clothing has been correlated to tolerance time and WBGT. For men working at 300 kcal/hr, an environment of 33°C WBGT (estimated) resulted in a dropout rate of 50% within 2 hours; only 35% of the subjects were able

TABLE 1. TYPICAL AIRCREW ENVIRONMENTS

Phase	Environment	Duration
Briefing	Cool	2 h
Preflight	Ambient	30-45 min
Flight	Cockpit	1-2 h
Postflight	Ambient	15 min
Debriefing	Cool	up to 2 h

to complete 3 hours (16). Eichna et al. (6) demonstrated that men exercising at similar rates without rest in a hot environment for 4 hours showed symptoms of heat stress with an average WBGT of 35°C (calculated) and most experienced extreme difficulty at a WBGT of 37°C. These studies are the basis for a series of TLVs (12) for heat exposure based upon metabolic work rate, time of exposure, and work-rest schedule. These TLVs recommend a WBGT of 33°-36°C for workers following a schedule as outlined in Table 1. USAF fighter crews are apt to be more physically fit and better heat acclimatized than most other subjects used in the reported studies, and thus can be expected to perform their work in hotter environments without increased risk of physiological compromise despite their heavier clothing. Indeed, Snook and Ciriello (25) concluded that the ACGIH TLVs are low and can be increased by 2°C for fit, acclimatized personnel.

Considering the combined effects of metabolic rate, clothing, acclimatization, and duration of exposure, a cockpit WBGT of 38°C (100.4°F) was selected as the lower limit of the FITS Danger Zone for fighter/trainer operations. Conditions this hot or worse render physiological compensation inadequate, thus allowing progressive heat storage and dehydration with potentially serious impairment of stress tolerance and critical task performance.

The Danger Zone limit addresses the problem of physiological dangers; however, lower levels of heat stress are also troublesome unless proper precautions are observed. Nunneley et al. (22) showed in simulated hot-weather flights that a WBGT of 31°C alters the learning curve, and that repeated missions with minimal rest periods result in cumulative fatigue. Other literature reviews indicate that measurable performance decrements occur with 2-hr exposure to conditions exceeding 30°C WBGT, effects appearing earlier as conditions worsen (7, 29 [WBGT estimated]). NIOSH recommends that WBGT not exceed 31°C for jobs where continuous unimpaired mental performance is required (12). A limit of 32°C (89.6°F) cockpit WBGT was selected as a reasonable lower limit for unimpaired performance, considering all variables in the fighter/trainer scenario. The 32°-38°C (89.6°-100.4°F) range in cockpit WBGT was therefore designated the "Caution Zone." Within this zone the body can usually establish a steady state with a core temperature below 38°C, provided that physiological reserves are protected (see Discussion); however, cumulative fatigue and decreased learning ability may occur.

Construction of the FITS Tables

Most weather stations report relative humidity rather than dew point or T_{pwb}. The FITS tables therefore use air temperature (T_{db}) and relative humidity (RH) as entry values. Tables 2 and 3 were constructed using a psychrometric computer program (27) to obtain T_{wb} as a function of T_{db} and RH.

TABLE 2. WET BULB TEMPERATURE (°C)

Air temp (°C)	Relative humidity (%) ≤10	20	30	40	50	60	70	≥80
20.0	7.67	9.33	10.89	12.39	13.83	15.17	16.44	17.67
22.5	9.17	11.00	12.72	14.39	15.83	17.28	18.72	20.17
25.0	10.61	12.61	14.44	16.28	17.94	19.50	20.94	22.39
27.5	11.94	14.17	16.17	18.11	19.97	21.67	23.22	24.78
30.0	13.33	15.72	18.00	19.56	22.00	23.78	25.44	27.06
32.5	14.72	17.44	19.83	22.06	24.11	26.06	27.78	29.50
35.0	16.11	19.00	21.67	24.00	26.17	28.22	30.11	31.89
37.5	17.39	20.44	23.39	25.89	28.22	30.39	32.33	34.28
40.0	18.72	22.11	25.28	27.94	30.39	32.61	34.61	36.67
42.5	20.06	23.72	26.94	29.89	32.50	34.89	37.00	38.94
45.0	21.33	25.33	28.78	31.89	34.61	36.61	39.33	41.22
47.5	22.56	26.89	30.56	33.89	36.72	39.33	41.89	43.78
50.0	23.94	28.58	32.36	35.94	38.83	41.06	43.56	46.06

The information given in Table 2 was used in equations 9 and 10 to construct FITS tables in °C for direct sun (Table 4) and moderate overcast (Table 5). All calculations were repeated to produce equivalent tables in °F (Tables 6 and 7). The boundaries for Caution and Danger Zones were then added.

TABLE 3. WET BULB TEMPERATURE (°F)

Air temp (°F)	Relative humidity (%)							
	≤10	20	30	40	50	60	70	≥80
70	47.0	50.1	52.9	55.9	58.6	60.9	63.4	65.8
75	50.0	53.4	56.6	59.7	62.5	65.3	68.0	70.4
80	52.8	56.7	60.0	63.4	66.7	69.6	72.3	75.0
85	55.4	59.7	63.6	67.3	70.7	74.0	76.9	79.8
90	58.2	63.0	67.2	71.2	75.0	78.4	81.6	84.7
95	61.0	66.2	71.0	75.2	79.1	82.8	86.2	89.4
100	63.6	69.3	74.6	79.1	83.3	87.4	90.8	94.2
105	66.3	72.4	78.0	83.0	87.6	91.6	95.3	98.8
110	68.8	75.5	81.7	87.0	91.8	96.1	100.0	103.7
115	71.4	78.9	85.3	91.0	96.0	100.4	104.3	108.1
120	74.2	82.2	88.8	95.0	100.1	104.7	109.0	113.0

TABLE 4. FITS (°C) FOR DIRECT SUN

Air temp (°C)	Zone	Relative humidity (%) ≤10	20	30	40	50	60	70	≥80
20.0		18.5	19.9	21.2	22.4	23.6	24.7	25.8	26.8
22.5		20.7	22.2	23.6	25.0	26.2	27.4	28.6	29.8
25.0		22.7	24.4	25.9	27.4	28.8	30.1	31.3	32.5
27.5	Normal	24.7	26.6	28.2	29.8	31.4	32.8	34.1	35.4
30.0		26.8	28.7	30.6	31.9	33.9	35.4	36.8	38.1
32.5		28.8	31.1	33.0	34.9	36.6	38.2	39.6	41.0
35.0		30.8	33.2	35.4	37.4	39.2	40.9	42.4	43.9
37.5		32.8	35.3	37.8	39.8	41.8	43.6	45.2	46.8
40.0	Caution	34.8	37.6	40.2	42.4	44.4	46.3	47.9	49.6
42.5		36.9	39.8	42.5	44.9	47.1	49.1	50.8	52.4
45.0		38.7	42.0	44.9	47.5	49.7	51.4	53.6	55.2
47.5	Danger	40.6	44.2	47.2	50.0	52.3	54.5	56.6	58.2
50.0		42.7	46.5	49.6	52.6	55.0	56.8	58.9	61.0

TABLE 5. FITS (°C) FOR MODERATE OVERCAST

Air temp (°C)	Zone	Relative humidity (%) ≤10	20	30	40	50	60	70	≥80
20.0		15.7	17.1	18.3	19.6	20.8	21.9	22.9	24.0
22.5		17.8	19.3	20.8	22.1	23.3	24.5	25.7	26.9
25.0		19.9	21.5	23.1	24.6	26.0	27.3	28.4	29.6
27.5		21.9	23.7	25.4	27.0	28.5	29.9	31.2	32.5
30.0	Normal	23.9	25.9	27.8	29.1	31.1	32.6	33.9	35.3
32.5		26.0	28.2	30.2	32.0	33.7	35.3	36.8	38.2
35.0		28.0	30.4	32.6	34.5	36.3	37.9	39.6	41.1
37.5		29.9	32.5	34.9	37.0	38.9	40.7	42.3	43.9
40.0		31.9	34.7	37.4	39.6	41.6	43.4	45.1	46.8
42.5		34.1	37.0	39.6	42.1	44.2	46.2	48.0	49.6
45.0	Caution	35.9	39.2	42.0	44.6	46.9	48.5	50.8	52.3
47.5		37.8	41.4	44.4	47.2	49.5	51.7	53.8	55.3
50.0	Danger	39.8	43.6	46.8	49.7	52.1	54.0	56.0	58.1

TABLE 6. FITS (^{o}F) FOR DIRECT SUN

Air temp (^{o}F)	Zone	Relative humidity (%)							
		≤10	20	30	40	50	60	70	≥80
70		67.1	69.6	71.9	74.4	76.7	78.6	80.6	82.6
75		71.3	74.1	76.8	79.3	81.7	84.0	86.2	88.2
80	Normal	75.4	78.6	81.4	84.2	86.9	89.3	91.6	93.8
85		79.3	82.9	86.1	89.2	92.0	94.7	97.1	99.5
90		83.4	87.4	90.9	94.2	97.3	100.2	102.8	105.4
95		87.5	91.8	95.8	99.3	102.5	105.6	108.4	111.0
100		91.4	96.2	100.3	104.3	107.8	111.2	114.0	116.8
105	Caution	95.5	100.3	105.1	109.3	113.1	116.4	119.5	122.4
110		99.3	104.9	110.0	114.4	118.4	121.9	125.1	128.2
115	Danger	103.2	109.4	114.7	119.5	123.6	127.2	130.5	133.6
120		107.3	113.9	119.4	124.5	128.8	132.6	136.1	139.5

TABLE 7. FITS (^{o}F) FOR MODERATE OVERCAST

Air temp (^{o}F)	Zone	Relative humidity (%) ≤10	20	30	40	50	60	70	≥80
70		61.9	64.5	66.8	69.3	71.5	73.4	75.5	77.5
75		66.2	69.0	71.7	74.2	76.5	78.9	81.1	83.1
80		70.3	73.5	76.2	79.1	81.8	84.2	86.4	88.7
85	Normal	74.2	77.8	81.0	84.1	86.9	89.5	92.0	94.4
90		78.3	82.3	85.8	89.1	92.2	95.0	97.7	100.2
95		82.4	86.7	90.7	94.2	97.4	100.3	103.3	105.9
100		86.3	91.0	95.4	99.2	102.6	106.0	108.8	111.7
105		90.3	95.4	100.0	104.2	108.0	111.3	114.3	117.2
110	Caution	94.2	99.7	104.9	109.2	113.2	116.8	120.0	123.1
115		98.1	104.3	109.6	114.3	118.5	122.1	125.3	128.5
120	Danger	102.2	108.8	114.3	119.4	123.6	127.5	131.0	134.3

DISCUSSION

The Fighter Index of Thermal Stress is designed for easy use by operational units to predict when cockpit environmental conditions during low-level missions may jeopardize aircrew performance. FITS meets our previously listed practicality criteria: (1) routine weather-data inputs; (2) easy readability; (3) 1-page presentation; and (4) relation to operational go/no-go decisions. Note that FITS is not a subjective measure of heat stress, and equal intervals between FITS values do not necessarily correspond to equal changes in heat-stress sensation. Further work would be necessary to develop a subjective index analogous to the equivalent chill temperature shown in windchill charts.

The literature of heat-stress effects on performance is voluminous and complex. Several comprehensive reviews exist (9, 15, 17). Results must be treated with great caution due to the large number of variables involved, including thermal conditions and duration, subject motivation, task familiarity, and acclimatization. A widely accepted generalization is the time-tolerance curve of Wing (29). In applying this information to aircrews, allowance has been made for their higher metabolic rate and heavy clothing as well as the radiant heat load. Experiments in this laboratory simulating fighter sorties show that heat disrupts the learning curve, results particularly applicable to aircrews under instruction or those faced with new situations in the form of airborne emergencies (22).

FITS must be recognized as a specialized tool. Simplifying assumptions limit its use to most low-level flight (<915 m) in fighter and trainer aircraft, both single and dual seat, with high-visibility bubble canopies and aircrews wearing lightweight flight suits. Application of this index to large-bodied aircraft is inappropriate because personnel are not exposed to the same radiant heat, clothing requirements, or metabolic loads assumed in FITS.

The three zones indicated on the FITS Tables (4-7) are interpretation guides. They are not exact demarcation lines, but represent the FITS values at which most personnel will begin to experience the heat-stress problems as outlined. Before encountering problems, an individual aircrew member may withstand more or less heat stress than is indicated. This is because the terms "ground standby" and "low-level flight" encompass a range of activities, clothing requirements, and physiological conditions that cannot be incorporated into a simple index. As with any index, the FITS is like a map rather than an aerial photograph, and its precision suits the general environment in which it is to be used.

In this light, the Normal Zone encompasses subjectively hot but usually safe conditions in which common sense dictates that reasonable precautions be followed. The FITS zones assume that aircrews possess a reasonable degree of heat acclimatization. Commanders should not push activities in the first hot days of summer, and individuals newly arrived from cooler climates should be allowed 7 to 10 days for acclimatization. All personnel should be briefed on the importance of fluid intake.

The Caution Zone includes conditions that are tolerable for low-level flight if adequate precautions are taken. All aircrew members should be alerted to conditions, and ground operations (preflight and cockpit standby) should be limited to 90 minutes or less. A minimum 2-hour recovery in a cool environment is required, based upon the body's slow dissipation of stored excess heat. Experiments simulating cockpit thermal environments show that even under ideal recovery conditions, rectal temperature remains above normal 1 hour post stress, although subjects report themselves comfortable within a few minutes (22).

Fluid intake is a vital component of heat tolerance and recovery from stress. In the cockpit, sweat evaporation is the major heat-dissipation mechanism and rapidly depletes body fluid reserves that are essential to normal acceleration tolerance. Ample palatable fluids must be available in the aircrew recovery area. Water, dilute fruit juice, and iced tea are recommended over carbonated drinks or electrolyte solutions (26). To insure adequate rehydration, aircrews must force fluid intake, drinking more than dictated by acute postmission thirst alone (26).

The Danger Zone represents environmental conditions that induce progressive heat storage and dehydration sufficient to affect crew performance during normal low-level missions (1, 7, 20, 29); therefore, all flights below 915-m (3000-ft) AGL should be cancelled. For high-altitude flights, ground period should be limited to 45 minutes or less and fluids should be taken during flight if possible. The 2-hour recovery period is essential for personnel working in this environment.

Taken literally, FITS estimates cockpit conditions only during low-level flight, but the numbers also indicate levels of heat stress during ground and low-altitude portions of all flights. The latter aspect is the basis for recommending cancellation of all nonessential flights whenever the index exceeds 46°C (115°F). At FITS 46°C and above, even the minimum preflight and climbout time constitutes a significant drain on physiological reserves; this can compromise performance in later phases of the flight, such as high-altitude aerial combat maneuvers.

Tables 4-7 give the cockpit conditions expected for moderately overcast (no shadows) and direct-sun (no clouds) conditions. Since most cloud conditions encountered in hot environments range from light, high cirrus to moderately scattered cumulus clouds, Table 8 or Table 9, with accompanying comments, is recommended for general Air Force use. These tables are modifications of Tables 4 and 6 and can be easily reproduced in compact form ranging down to wallet size for inclusion in handbooks and posting on bulletin boards.

TABLE 8. FIGHTER INDEX OF THERMAL STRESS FOR LIGHTWEIGHT FLIGHT SUIT (CLEAR SKY TO LIGHT OVERCAST)

Instructions: At intersection of local ambient temperature and relative humidity, read FITS value and determine zone.

Air temp (°C)	Zone	Relative humidity (%) ≤10	20	30	40	50	60	70	≥80
20.0		19	20	21	22	24	25	26	27
22.5		21	22	24	25	26	27	29	30
25.0		23	24	26	27	29	30	31	32
27.5	Normal	25	27	28	30	31	33	34	35
30.0		27	29	31	32	34	35	37	38
32.5		29	31	33	35	37	38	40	41
35.0		31	33	35	37	39	41	42	44
37.5		33	35	37	40	42	44	45	47*
40.0	Caution[1]	35	37	40	42	44	46*	48*	50
42.5		37	40	42	45	47*	49	51	52
45.0		39	42	45	48*	50	51	54	55
47.5	Danger[2]	41	44	47*	50	52	55	57	58
50.0		43	47*	50	53	55	57	59	61

[1] Caution 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.

[2] Danger 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 9. FIGHTER INDEX OF THERMAL STRESS FOR LIGHTWEIGHT FLIGHT SUIT (CLEAR SKY TO LIGHT OVERCAST)

Instructions: At intersection of local ambient temperature and relative humidity, read FITS value and determine zone.

Air temp (°F)	Zone	Relative humidity (%) ≤10	20	30	40	50	60	70	≥80
70		67	70	72	74	76	78	81	83
75		71	74	77	79	82	84	86	88
80		75	79	81	84	87	89	92	94
85	Normal	79	83	86	89	92	95	97	99
90		83	87	91	94	97	100	103	105
95		87	92	96	99	102	105	108	111
100		91	96	100	104	108	111	114	117*
105	Caution[1]	95	100	105	109	113	116*	120*	122
110		99	105	110	114	118*	122	125	128
115	Danger[2]	103	109	115	119*	124	127	130	134
120		107	114	119*	124	129	133	136	140

[1]Caution 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.

[2]Danger Zone:
(1) Cancel low-level flights (below 3000-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.

CONCLUSIONS

The FITS is the first known attempt to develop scientific guidelines specifically for protection of aircrews operating in hot environments. With new high-performance aircraft challenging aircrews both physically and mentally, the FITS is particularly appropriate now. The index is also highly relevant to training situations, since learning is sensitive to heat stress as well as hypoxia (10).

Derivation of the FITS is based upon recently acquired flight data. Initial FITS application in the field should allow validation of the Caution and Danger Zone boundaries, and efforts to collect cockpit thermal data under operational conditions will continue.

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