COMPUTER PROGRAM DOCUMENTATION
41-NODE TRANSIENT METABOLIC MAN PROGRAM

Project Work Order 52-BE3

Prepared By

Lockheed Engineering and Sciences Company, Inc.
Houston, Texas

For

Crew and Thermal Systems Division
National Aeronautics and Space Administration
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PREFACE

The original document, released in May 1970, was prepared by Lois W. Morgan, George Collett and Dave W. Cook, Jr. of Lockheed Electronics Co., Houston Aerospace Systems Division, Houston, Texas for the Computer and Analysis Division of NASA. This revised document was produced in fulfillment of a task request of Summer 1988 for Project Work Order No. 052-52-BE3, which is as follows:

UPDATE 41-NODE MAN DOCUMENTATION

- Update engineering sections with equations used and descriptions.
- Document all subroutines.
- Provide references for all equations.
- Use appendices for lengthy descriptions.
- Provide more detailed table of contents.

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NOMENCLATURE

Engineering symbols with subscripts are used to represent FORTRAN variables in sections 1, 2 and 3, and in the appendices. The FORTRAN variable names, along with the corresponding engineering symbols, are listed in Table 4.1 (input variables) and Table 5.1 (primary variables).

<u>Acronyms</u>

METMAN	41-Node Transient Metabolic Man Program.
EVA	Extravehicular Activity.
IVA	Intravehicular Activity (suited).
LCG	Liquid Cooled Garment.
OPS	Oxygen Purge System
PLSS	Portable Life Support System.

<u>Subscripts Definitions</u>

c	Core compartment.
m	Muscle compartment.
f	Fat compartment.
s	Skin compartment.
i	Each of the 41 nodes comprising the thermal regulatory model.
j	Each of the 10 body segments comprising the thermal regulatory model

<u>Engineering Symbols</u>

A	Total body surface area, as determined by a nomographic relation.
A_C	Area of convection of each skin compartment.
A_{OS}	Area of outside surface of each suit segment.
A_R	Area of radiation of each skin compartment.
A_{wall}	Convective area of cabin.
β	Exponent controlling mass transfer (suited case).
C_i	Capacitance of each body compartment.
c_p	Specific heat of each body compartment.
c_{p_b}	Specific heat of blood compartment.
c_{p_g}	Specific heat of gas.
c_{p_S}	Specific heat of suit segment.
c_{p_w}	Specific heat of LCG coolant.
ΔT	Temperature difference between nodes of two adjacent body compartments.
Δt	Time step.

ε_{IS}	Emissivity of inside of suit.
E_{max}	Maximum evaporative capacity of each skin compartment.
ε_{OS}	Emissivity of outside of suit.
ε_{ug}	Emissivity of undergarment/skin.
$\mathcal{F}$	Radiation interchange factor.
F	View factor.
f	Percent of flow of coolant to each LCG segment.
F_{BF}	Blood flow factor.
G	Ratio of actual gravitational acceleration to 32.2 ft/s^2.
g_c	Conductivity of a core compartment.
g_f	Conductivity of a fat compartment.
g_m	Conductivity of a the muscle compartment.
g_s	Conductivity of a skin compartment.
$G_j^{i \rightarrow i+1}$	Conductance between two adjacent nodes of a segment.
H	Height of crew member.
$\bar{h}_{D,j}$	Average mass transfer coefficient for each segment.
h_{fg}	Heat of evaporation of water.
$\bar{h}_j$	Average convection coefficient for each segment.
κ_1	Body size proportioning factor.
κ_2	Body size proportioning factor.
κ_3	Body size proportioning factor.
κ_4	Body size proportioning factor.
k	Conductivity of each body compartment.
K_{con}	Distribution factor of vasoconstriction to each skin compartment.
K_{dil}	Distribution factor of vasodilation to each skin compartment.
K_i	Conductance between adjacent body compartments.
K_m	Weight distribution coefficient
K_{ms}	Distribution coefficient of shiver to the muscle compartments.
K_{mw}	Distribution coefficient of work to the muscle compartments.
K_S	Conductance of each suit segment.
K_s	Distribution coefficient of skin weight to each skin compartment.
K_s'	Distribution factor of latent heat of sweat to each skin compartment.
K_{ug}	Conductance of undergarment.
L	Thickness of body compartment layer.
l_j	Body segment length.
M	Weight of subject.
m	Compartment mass.
$\dot{m}_{basal,c}$	Basal blood flow in a core layer.
$\dot{m}_{basal,f}$	Basal blood flow in each fat compartment.

$\dot{m}_{basal,m}$	Basal blood flow in each muscle compartment.
$\dot{m}_{basal,s}$	Basal blood flow in each skin compartment.
M_c	Body weight.of the core.
$\dot{m}_c$	Blood flow in each core compartment.
$\dot{m}_{CO2in}$	Flow rate of CO2 into cabin.
$\dot{m}_{CO2net}$	Net flow rate of CO2 into cabin.
$\dot{m}_{CO2out}$	Flow rate of CO2 out of cabin.
$\dot{m}_{CO2prod}$	Production rate of CO2 of crew.
$\dot{m}_{dilate}$	Increase in blood flow to a skin node due to vasodilation.
M_f	Weight of body fat.
$\dot{m}_f$	Blood flow in each fat compartment.
$\dot{m}_{gas}$	Flow rate of the dry gas in the suit.
$\mathcal{M}_{gas}$	Average molecular weight of gas mixture.
$\dot{m}_{H_2Oin}$	Flow rate of water vapor into cabin.
$\dot{m}_{H_2Onet}$	Net flow rate of water vapor into cabin.
$\dot{m}_{H_2Oout}$	Flow rate of water vapor out of cabin.
$\dot{m}_{H_2Oprod}$	Water vapor production rate of crew.
M_i	Body compartment weight.
$\dot{m}_i$	Blood flow to each body compartment.
M_l	Lean body weight.
$\dot{m}_{lcg}$	Coolant flow rate in the LCG.
M_m	Body weight.of the muscle.
$\dot{m}_m$	Blood flow to each muscle compartment.
$\dot{m}_{O2cons}$	Oxygen consumption rate of crew.
m_S	Mass of suit segment.
M_s	Total weight of the skin.
$\dot{m}_s$	Blood flow to each skin compartment.
$\dot{m}_{wall}$	Water vapor condensation rate on cabin wall.
N	Number of crew members in cabin.
P_{av}	Water vapor pressure of inspired gas.

P_{cab}	Gas pressure in cabin.
P_{in}	Water vapor pressure into each suit segment.
P_{out}	Water vapor pressure out of each suit segment.
P_s	Water vapor pressure at the undergarment or skin surface.
P_g	Pressure of the inspired gas.
P_{Tdew}	Water vapor pressure of the cabin at the dew point temperature.
P_{Tr}	Saturation pressure of water vapor at the respiratory temperature.
P_{Tug}	Saturation pressure of water vapor at the skin or undergarment surface temperature.
P_{Twall}	Saturation pressure of water vapor at the wall temperature.
q_{abs}	Incident absorbed heat on each suit segment.
q_{BMR}	Basal metabolic heat rate of body.
$q_{BMR,m}$	Basal metabolic rate of each muscle compartment.
q_c	Total basal metabolic rate of the body core.
$Q_{comfort}$	Comfort criteria.
q_{cond}	Conductive heat transfer between adjacent body compartments.
$q_{cond}^{c \rightarrow m}$	Conductive heat transfer rate between core and muscle compartments of each segment.
$q_{cond}^{f \rightarrow s}$	Conductive heat transfer rate between adjacent fat and skin compartments of each segment.
$q_{cond}^{m \rightarrow f}$	Conductive heat transfer rate between muscle and fat nodes of each segment.
q_{conv}	Intrinsic convection--convection from each body compartment to blood.
q_{dif}	Heat transfer of each skin compartment by diffusion.
q_{enth}	Rate of change of enthalpy of cabin gas.
q_f	Total basal metabolic rate of the body fat.
q_{IS} to	Convection heat transfer rate of each segment, from inside suit surface gas stream.
q_{lat}	Latent heat dissipation rate of each skin compartment by sweat evaporation and diffusion.
q_{lcg}	Heat transfer rate to each segment of the LCG.
q_m	Total basal metabolic rate of the muscle.
q_{met}	Metabolic heat generation rate of each body compartment.
$q_{met,m}$	Metabolic heat generation rate of each muscle compartment.
q_{mshiv}	Heat generation rate of shivering distributed to each muscle compartment.
q_{mwork}	Heat generation rate of work distributed to each muscle compartment.
q_{OSC}	Convection heat transfer rate of outside of suit with cabin gas.
q_{OSR}	Radiation heat transfer rate of outside of suit with cabin walls.
q_{rad}	Radiation heat transfer rate between each undergarment/skin segment and enclosure.

q_{rlat}	Latent heat transfer rate of respiratory tract and lungs.
q_{rsen}	Sensible heat transfer rate of respiratory tract and lungs.
q_s	Total basal metabolic rate of the skin.
q_{senc}	Convection heat transfer rate of each undergarment/skin segment and the gas stream.
q_{shiv}	Total heat generation rate by shivering.
Q_{stor}	Total heat stored by the body.
q_{storat}	Instantaneous heat storage rate of the body.
q_{swt}	Total heat dissipation rate by sweating, assuming complete evaporation.
$q_{swt,s}$	Heat dissipation rate of sweating distributed to each skin compartment.
q_{tsen}	Total convection heat transfer rate of crew.
q_{ug}	Heat transfer rate into undergarment from skin which is equal to the heat transfer rate from undergarment to environment.
q_{wall}	Convective heat transfer rate from cabin gas to cabin walls.
q_{work}	Total heat generation rate of work.
$\mathcal{R}$	Factor which accounts for vasoconstriction in the skin.
R	Gas constant.
σ	Stefan-Boltzmann constant.
r_i	Radius of the outer boundary of each body compartment.
T_{av}	Weighted average temperature of the skin of the trunk, arms and legs.
T_b	Temperature of the blood compartment.
T_c	Temperature of each core compartment.
T_{cab}	Cabin gas temperature.
T_{dew}	Cabin dew point temperature.
T_{enc}	Cabin wall temperature (shirt-sleeve mode) or suit interior temperature (suited modes).
T_f	Temperature of each fat compartment.
T_{gas}	Gas temperature.
$\overline{T}_{gas}$	Logarithmic mean gas temperature.
$T_{gas_{in}}$	Gas temperature into each suit segment.
$T_{gas_{out}}$	Gas temperature out of each suit segment.
T_i	Temperature of each body compartment.
T_{in}	Temperature of gas at cabin inlet.
T_{inlet}	Temperature of the coolant at the LCG inlet
$T_{inspire}$	Temperature of inspired air.
T_{IS}	Temperature of inside surface of each suit segment.
T_{IS}^{n-1}	Inside suit temperature of each segment just prior to current program iteration.
T_{IS}^{n}	Inside suit temperature of each segment at current program iteration.
T_m	Temperature of each muscle compartment.
T_{OS}	Temperature of outside surface of each suit segment.

T_{OS}^{n-1}	Outside suit temperature of each segment just prior to current program iteration.
T_{OS}^{n}	Outside suit temperature of each segment at current program iteration.
T_r	Respiratory temperature.
Ts	Temperature of each skin compartment.
Tset,c	Setpoint temperature of each core compartment.
Tset,i	Setpoint temperature of each body compartment.
Tset,s	Setpoint temperature of each skin compartment.
Tug	Temperature of undergarment or skin (whichever is exposed).
Twall	Wall temperature of cabin.
Ueff	Efficiency of muscles in performing mechanical work.
Umech	Mechanical work rate.
Vcab	Freestream velocity of gas in cabin.
Veffm	Ventilation efficiency.
V_i	Cumulative body compartment volume for each segment.

1 INTRODUCTION

The 41-Node Transient Metabolic Man Program (METMAN) is designed to simulate the heat transfer within a man, and the heat exchange between a crew member and his environment. The environmental modes include shirt-sleeve, suited intravehicular activity (IVA), extravehicular activity (EVA), and helmet-off. The use of a liquid-cooled garment (LCG) and postlanding environmental conditions are optional. Metabolic rate, body size, and environmental data are input, and the mode is selected. The transient-thermal properties of the man and his environment are calculated, and the output is printed at scheduled intervals. The output describes the reaction of the crew member to the environmental conditions, and the impact that the crew member has on the environment, i.e. heat transfer, water production, CO_2 production, and O_2 consumption.

The analysis implemented in METMAN is built around a 41-node concept. METMAN is constructed around a two-node, an eight-node, a 14-node and a 25-node program logic that has been run in the past with success.

The authors wish to acknowledge the contribution of Larry Kuznetz, a former NASA/CTSD engineer, who provided engineering analysis for this program, and wrote Section 2 of the original document.

2 GENERAL PROGRAM DESCRIPTION

METMAN has four different modes of operation. A crew member's metabolic rate, work efficiency, convective and radiative areas and the undergarment thickness, conductivity, and emissivity are input for all modes. The revised program also requires the crew member's height and weight to be input in order to scale the thermoregulatory model for body size (see Section 5.3.1). Special input parameters include the initial computational time increment, the print interval, the maximum case time, and the number of imposed cases. Options, output information and other input requirements are described below.

2.1 MODE 0: SHIRT-SLEEVE

The shirt-sleeve mode computes the metabolic characteristics of a man dressed in an undergarment in a cabin environment. Cabin characteristics that are required for input are the view factor, cabin gas temperature, cabin gas pressure, wall temperature, dew point, cabin gas free-stream velocity, and gravitational force.

The LCG logic can be used if the fluid flow rate through the garment is input. The inlet coolant temperature and specific heat of the coolant are also required input. The inlet coolant temperature can be fixed, varied by curve data, varied by metabolic and heat storage parameters, or calculated from internal logic simulating the entire coolant loop.

Cabin purge conditions can be simulated by exercising the postlanding option in the program. The required input includes the fan circulation rate, temperature and dew point of the atmosphere surrounding the cabin, the cabin volume, the cabin wall temperature for postlanding, the cabin wall area, and the number of crew members.

METMAN computation results are output as follows: Case time, head core temperature, average skin temperature, average undergarment temperature, sensible heat transferred from the man to his environment, total heat transferred by sweat, diffusion, and lung latent, heat storage rate, shiver rate, total heat storage in the man, cabin dry bulb temperature, cabin dew point, and the cabin CO_2 level.

2.2 MODE 1: NORMAL SUITED INTRAVEHICULAR ACTIVITY (IVA)

This mode computes the thermal behavior of the man-cabin model with the man suited. Half of the suit gas flow goes into the helmet then to the torso, and the other half goes directly into the torso. Sixty percent of the gas from the torso then flows over the arms and hands, and 40 percent flows over the legs and feet.

The pressurized suit inputs include the suit vent gas flow rate, the temperature of the gas into the suit, the dew point of the gas into the suit, the specific heat and pressure of the gas, and the partial pressure of O_2. Information that is separately input for the suit torso, sleeves, legs, helmet, gloves, and boots includes the incident heat absorbed, radiative area, convective area, weight, specific heat, thickness, conductivity, and emissivity of the inside and outside surfaces.

The LCG (liquid-cooled garment) and postlanding options are available in this mode.

Computation results are output as follows: time, temperature of gas out of the suit, specific humidity of gas at the suit outlet, temperature of the head core, average skin temperature, average temperature of the outside and inside of the suit, heat transferred through the suit (suit heat leak), total sensible heat transferred from the man, total sweat evaporated from the man, total latent heat transferred from the man, heat storage rate, shiver rate, total heat storage, and the CO_2 content of the helmet.

2.3 MODE 2: EXTRAVEHICULAR ACTIVITY (EVA)

This mode calculates the thermal activity of a suited crew member during extravehicular activity. The gas flows into the helmet, and from the helmet into the torso, where the flow then splits and 75 percent of the gas flows over the arms and hands, and 25 percent flows over the legs and feet. Input is the same as listed for Mode 1 with the following exception: The incident heat absorbed by the suit is usually used instead of the cabin conditions in this mode; the cabin wall temperature, cabin pressure, and cabin gas dew point and velocity are generally used for Mode 1 in lieu of absorbed heat.

The LCG may be used, and a suit purge using dry air is available. The purge option simulates the OPS (Oxygen Purge System) of the PLSS (Portable Life Support System) of the Apollo-era. Any of the curve options may be used.

Output is the same as indicated for Mode 1.

2.4 MODE 3: HELMET OFF

This mode calculates the thermal conditions for an crew member with his pressure suit on, but without the helmet. The gas flow is 60 percent into the hands and 40 percent into the feet. Then the gas enters the torso from the extremities and flows out at the head. Suit calculations are used for all parts of the body except the head where the cabin conditions are taken into account.

Postlanding and LCG options are available. Input and output are the same as indicated for Mode 1.

2.5 CURVE OPTIONS

When appropriate, certain parameters may be input for any mode as time varying curve data rather than as constants. These parameters are: (1) helmet conductivity, (2) gas flow rate, (3) mode, (4) cabin pressure (5) suit pressure, (6) suit oxygen pressure, (7) metabolic rate, (8) cabin temperature, (9) inlet suit gas dew point, (10) cabin dew point, (11) inlet suit gas temperature, (12) cabin wall temperature, (13) inlet coolant temperature to the LCG, (14) work efficiency of muscles, (15) velocity of cabin gas, (16) coolant flow rate in the LCG, (17) suit conductivity, and (18) incident heat absorbed on the suit surface. Each parameter may be used independently.

3 MODEL OF THE THERMAL REGULATORY SYSTEM IN MAN

In METMAN, the body is divided into 10 cylindrical segments: head, trunk, right and left arms, right and left legs, right and left hands, and right and left feet. Each segment consists of four concentric compartments: core, muscle, fat layer, and skin (see Figure 3.1). Considering the central blood as a compartment, the man model consists of 41 distinct compartments, each with a node at the midpoint between inner and outer radii. Each compartment is assumed to have a uniform temperature equal to that of its node which results in a discontinuous temperature distribution across a body segment (see Figure 3.2).

3.1 GENERAL HEAT BALANCE EQUATIONS

The human body may be considered in the same manner as a heat engine. That is, heat is produced (q_{met}) by the oxidation of fuel (food) for energy, and heat is dissipated by conduction, convection, radiation, and mass transfer at the skin surface. Heat produced in excess of that which can be dissipated will be stored in the tissues (Q_{stor}) with a resulting rise in body temperatures. Values of q_{stor} in excess of 300 Btu are equivalent to high body temperatures indicative of life function deterioration. Initial heat storage for each of the nodes is set to zero.

Heat generated in each body compartment (q_{met}) is transmitted by convection to the blood (q_{conv}), and by conduction to adjacent compartments (q_{cond}). For skin compartments, convection to a gas stream (q_{senc}), radiation to walls or the suit interior surfaces (q_{rad}),

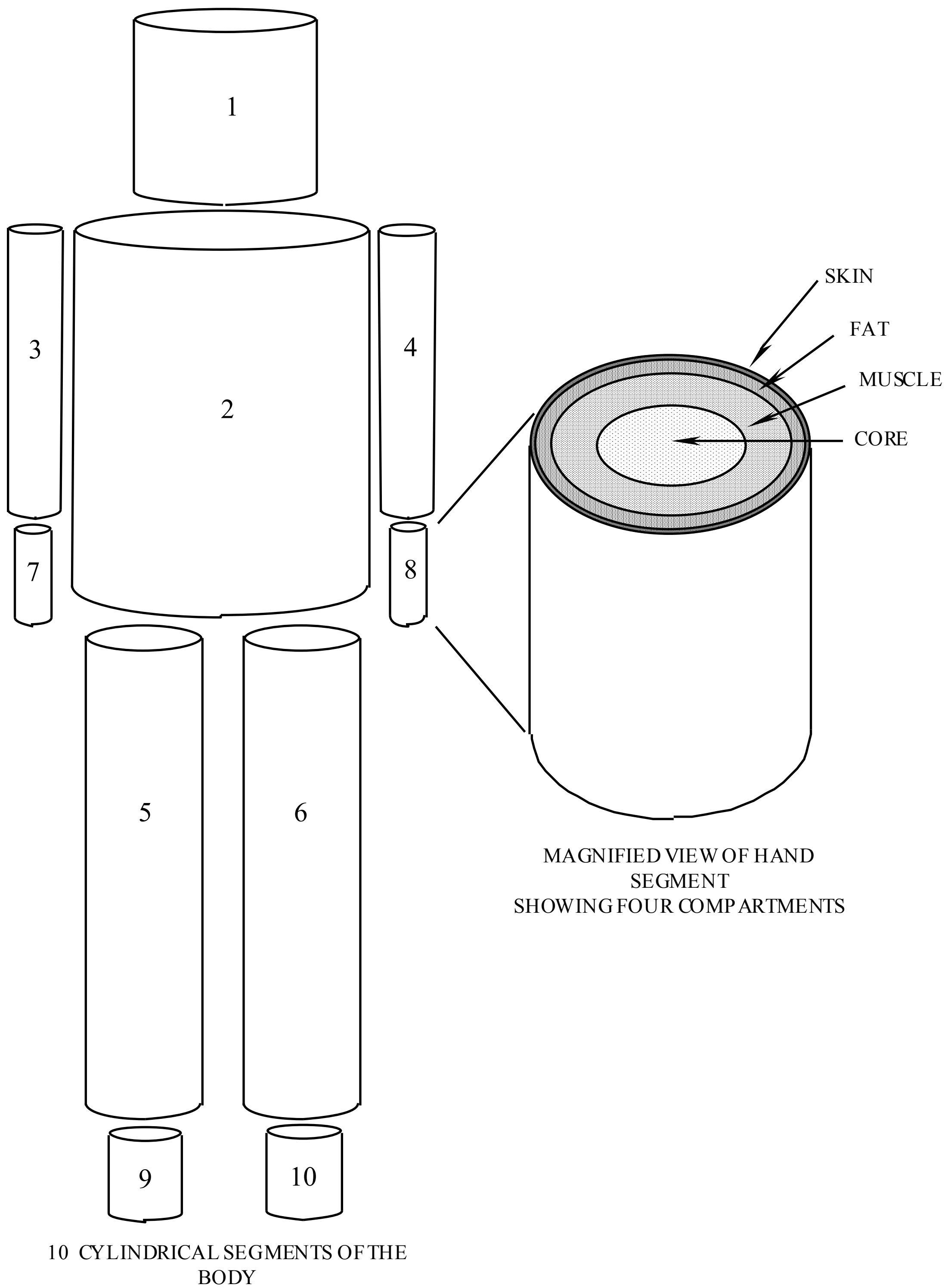


Figure 3.1 Geometric Model of Man

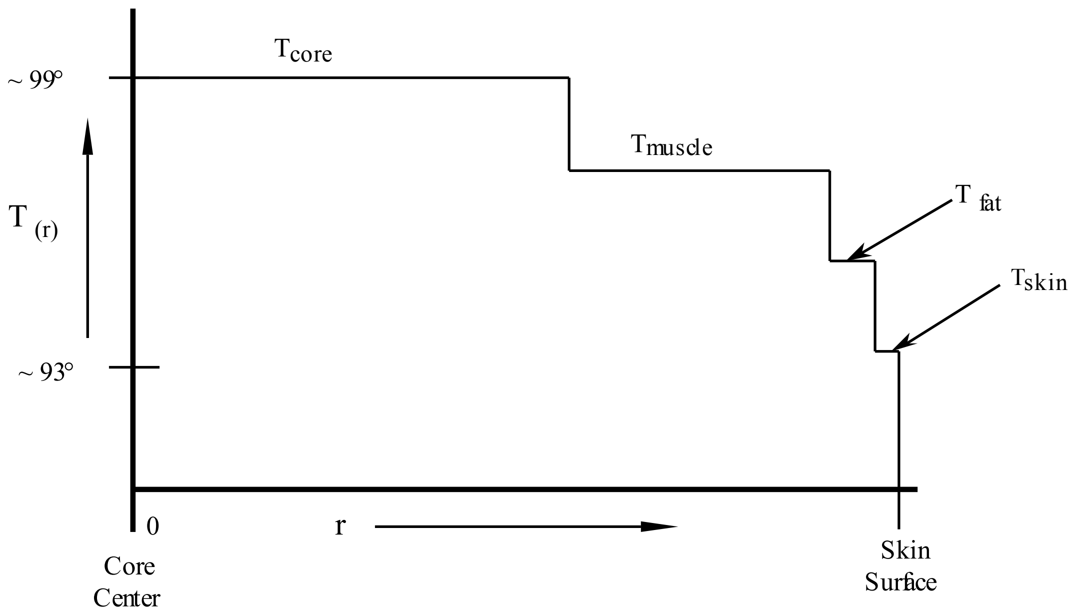


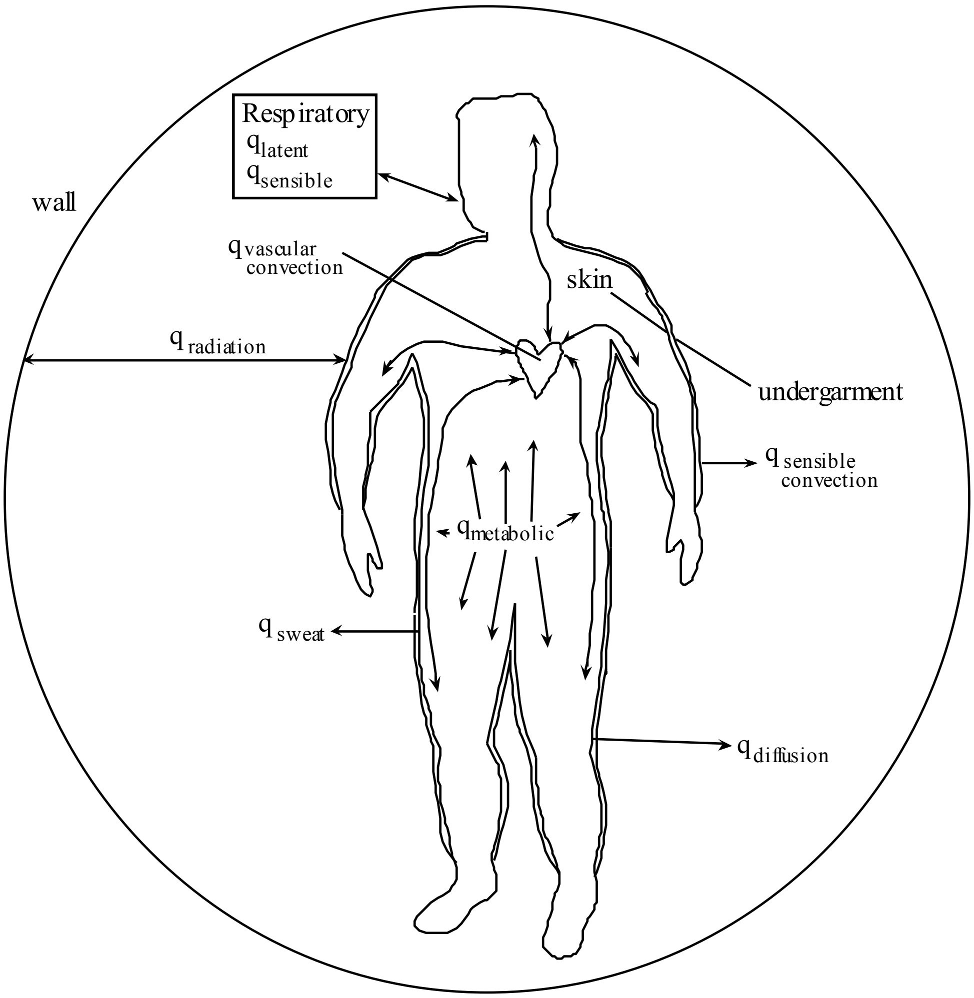
Figure 3.2 Discrete Thermal Model

latent evaporation (q_{lat}), and conduction to a thermal undergarment (q_{ug}), with selective conduction to a LCG (q_{lcg}), are all considered as avenues of heat dissipation.

The general equation for each body compartment is simply written in the form of a heat balance as:

$$\text{Heat stored} = \text{Heat in} - \text{Heat out}$$

The heat balance is shown in Figure 3.3 and is described for each body compartment in Appendix A.



$$\underbrace{q_{metabolic}}_{\text{Heat Produced}} \underbrace{- q_{radiation} - q_{diffusion} - q_{sens.\ convection} - q_{resp.\ latent} - q_{resp.\ sensible} - q_{vasc.\ convection}}_{\text{Heat Dissipated}} = \underbrace{q_{stored}}_{\text{Heat Stored}}$$

Figure 3.3 Heat Balance for Man in Space

For a given body segment, the general equations for the core, muscle, fat, and skin compartments are as follows:

- Core

$$\left(m\, c_p \frac{dT}{dt}\right)_i = \left(q_{met} - q_{cond}^{c\text{–>}m} - q_{conv}\right)_i \qquad \text{(Btu/hr)}$$

- Muscle

$$\left(m\ c_p \frac{dT}{dt}\right)_{i+1} = \left(q_{met} + q_{cond}^{c\rightarrow m} - q_{cond}^{m\rightarrow f} - q_{conv}\right)_{i+1} \text{(Btu/hr)}$$

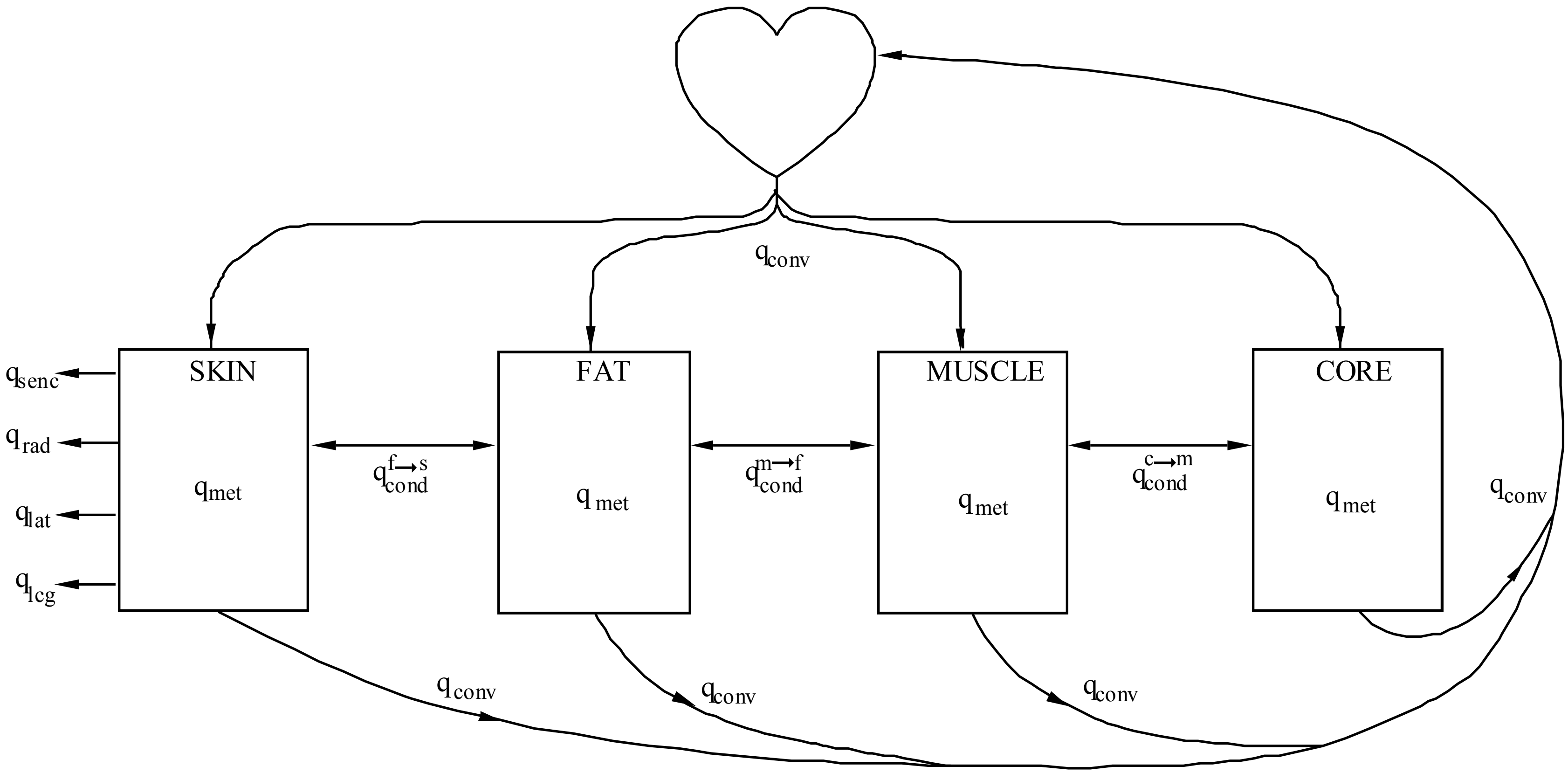
- Fat

$$\left(m\ c_p \frac{dT}{dt}\right)_{i+2} = \left(q_{met} + q_{cond}^{m\rightarrow f} - q_{cond}^{f\rightarrow s} - q_{conv}\right)_{i+2} \text{(Btu/hr)}$$

- Skin

$$\left(m\ c_p \frac{dT}{dt}\right)_{i+3} = \left(q_{met} + q_{cond}^{f\rightarrow s} - q_{conv} - q_{rad} - q_{senc} - q_{lat} - q_{lcg}\right)_{i+3} \quad \text{(Btu/hr)}$$

where m and c_p are the mass and specific heat of each body compartment, and $q_{cond}^{c\rightarrow m}$, $q_{cond}^{m\rightarrow f}$ and $q_{cond}^{f\rightarrow s}$ are the conductive heat transfer rates from core to muscle, muscle to fat, and fat to skin respectively, and the subscript i refers to the body compartment. The variables which make up the heat balance equation are heat transfer pathways. These pathways are illustrated in Figure 3.4 and are the subject of Section 3.2.



Typical heat balance for skin segment:

$$m \; c_p \frac{dT}{dt} = q_{met} + q_{cond}^{f\rightarrow s} + q_{conv} - q_{senc} - q_{rad} - q_{lat} - q_{lcg}$$

Figure 3.4 Major Thermal Regulatory Pathways

3.2 HEAT TRANSFER PATHWAYS

3.2.1 Heat Generation

The heat generation of the body is also known as metabolic rate. Metabolic rate is a sum of the basal metabolic rate and the heat produced through work or shivering by muscles.

- Basal Metabolic Rate, q_{BMR}

  Most of the chemical reactions necessary to maintain life are exothermic. Because of this, all living cells generate heat. The heat production for the entire body from these essential reactions, about 278 Btu/hr for an average size male, is called the basal metabolic rate (q_{BMR}). This model uses the following relation to determine the q_{BMR}:

  $$q_{BMR} = q_{BMR}' A \qquad \text{(Btu/hr)}$$

  where $q_{BMR}' = 14.26$ Btu/hr-ft^2 is the basal metabolic rate per unit surface area, and A is the body surface area determined from the nomographic relationship [1]:

  $$A = 0.109\, M^{0.45}\, H^{0.725} \qquad (\text{ft}^2)$$

  where M is weight in lbm and H is height in inches (see Appendix B for body surface area description) Basal metabolic rate is distributed to the nodes based on compartment weight (see Appendix C).

- Metabolic Rate, q_{met}

  The total heat generated by the body, that is, the metabolic rate (q_{met}), consists of a basal metabolic rate and a work rate. As a consequence of the relative inefficiency of the body as a heat engine, most of the work generated in the muscle compartments is lost in the form of heat. Work which is not lost is converted directly into the mechanical energy required to perform a given task. The expression for work lost as heat, written as a rate equation, is as follows:

  $$q_{work} = q_{met} - q_{BMR} - U_{mech} \qquad \text{(Btu/hr)}$$

  The q_{work} term is the work rate actually produced in the muscle tissues that will enter into the heat balance equations, since it is all converted to heat. Mechanical work efficiency, U_{eff}, is defined such that the net mechanical work performed by a crew member on his surroundings is:

  $$U_{mech} = \frac{U_{eff}}{100.0}\,(q_{met} - q_{BMR}) \qquad \text{(Btu/hr)}$$

  The heat generation of work, q_{work}, is divided among the trunk, arm, and leg muscles with a minor amount generated in the hands and feet [2]:

$$q_{mwork} = K_{mw}\, q_{work} \text{ (Btu/hr)}$$

where K_{mw} is defined according to Table 3.1. The extremity muscles are not considered as a significant source of q_{work}.

- Shiver, q_{shiv}
  Heat may also be generated by the muscles through shivering. Shiver (q_{shiv}) is actually a measure of the amount of heat that must be generated metabolically to prevent the body from losing more heat than it is producing. This situation can only occur in cold environments. Shiver is added to q_{met} and distributed among the muscle compartments. The mathematical representation of q_{shiv} is described subsequently in Section 3.3, Active Controllers.

Table 3.1
Distribution Coefficient, K_{mw}, of Heat Produced by Work
Among the Muscle Compartments

Body Segment	..K_{mw}
Head	0.00
Trunk	0.30
Arms	0.08
Legs	0.60
Hands	0.01
Feet	0.01
	1.00

3.2.2 Heat Transfer Between Body Compartments

Heat transfer between body compartments occurs through conduction and vascular convection.

- Conduction, q_{cond}
  Conduction (q_{cond}) is characterized by heat transfer between two or three body compartments of a body segment, each assumed to be at a uniform temperature. Heat transfer is one dimensional, and is likened to conduction through a wall. It is assumed that lateral conduction is negligible. Therefore:

$$q_{cond} = \frac{kA}{L} \Delta T \qquad \text{(Btu/hr)}$$

Values of kA/L are from empirical determinations [3], and are adjusted for body size for each internodal element [1], (see Appendix D). Thus, the conduction terms for any body segment are:

$$q_{cond}^{c\rightarrow m} = K_i (T_c - T_m) \qquad \text{(Btu/hr)}$$

$$q_{cond}^{m\rightarrow f} = K_i (T_m - T_f) \qquad \text{(Btu/hr)}$$

$$q_{cond}^{f\rightarrow s} = K_i (T_f - T_s) \qquad \text{(Btu/hr)}$$

where K_i represents the kA/L values for each of the internodal elements of a specific segment.

- Intrinsic Convection, q_{conv}
Intrinsic convection (q_{conv}) is the heat transfer between the tissue compartments and the vascular system. Heat is transmitted to and from every living cell in the body by the bloodstream. With increased metabolism due to work, shivering, or emotional reactions, the blood flow is varied from the basal rate to provide those tissues expending additional energy with an adequate fuel supply. This also serves to carry away the increased production of waste products that is a consequence of elevated metabolic rates. Since increases in metabolic rate occur almost exclusively in the trunk, arm, and leg muscle compartments, it is not surprising that increases in blood flow rates are also limited to these body compartments. The heat transferred to each body compartment from the blood stream is given as:

$$q_{conv} = \dot{m}_i \, c_{p_b} (T_b - T_i) \qquad \text{(Btu/hr)}$$

where $\dot{m}_i$ is the blood flow through each body compartment, c_{p_b} is the specific heat of the blood, T_b is the temperature of the central blood pool, and T_i is the temperature of the individual body compartment.

It should be mentioned that the arterial bloodstream temperature is assumed to be uniform throughout the body. That is, a central blood pool contacts all tissue compartments. As previously mentioned, increases in metabolic rate propagate corresponding increases in blood flows for the arm, leg, and trunk muscle compartments. The blood flow to the extremity skin compartments can also be regulated by vasodilation or vasoconstriction, two of the mechanisms utilized by the thermoregulatory system for maintaining constant deep-body temperatures. These mechanisms are subsequently described in Section 3.3, Active Controllers.

Thus, it can be seen that the blood flow to the muscles and skin compartments may be varied in response to the metabolic rate and environmental conditions. Note that the blood flow to the core compartments remains unchanged regardless of external conditions. This condition is in accordance with the fact that energy requirements of the brain and other vital organs remain within narrow bounds. Consequently, blood flows to these regions do not vary significantly.

3.2.3 Heat Transfer Between Skin and Environment

1. Heat removal at the skin surface occurs by conduction to the LCG, convection, radiation, and moisture evaporation and diffusion. The model also accounts for the heat transfer from the skin to an active thermal control system, the LCG.

- Extrinsic Convection, q_{senc}

  Extrinsic convection, also called sensible convection (q_{senc}), is the heat transfer to a surrounding gas stream. It is limited due to the low specific heat of breathable gas mixtures. This is particularly true in a space suit where the gas flow rate is small. The amount of heat removed by sensible convection to a gas stream is:

$$q_{senc} = \bar{h}_j A_C (T_{ug} - \bar{T}_{gas}) \text{ (Btu/hr)}$$

where

A_C = surface area of each skin compartment exposed to the gas stream

$\bar{h}_j$ = average heat transfer coefficient

T_{ug} = undergarment temperature for the trunk, arm and leg nodes or the skin temperature for the hand, feet and head nodes

$\bar{T}_{gas}$ = log mean suit gas temperature for each segment in the suited modes or the cabin temperature in the shirt-sleeve mode

The evaluation of $\bar{h}_j$ and $\bar{T}_{gas}$ for shirt-sleeve and space-suit operation is described subsequently in Section 3.4, Modes of Operation.

- Radiation, q_{rad}
  Radiation from the skin, another form of sensible heat transfer, can become significant in cabin environments. For each skin compartment:

$$q_{rad} = A_R \sigma \mathcal{F} [(T_{ug} + 460.0)^4 - (T_{enc} + 460.0)^4] \qquad \text{(Btu/hr)}$$

where

σ = 1.713×10^{-9}, the Stefan-Boltzmann constant
A_R = radiation area of skin compartment, ft^2
$\mathcal{F}$ = interchange factor
T_{enc} = enclosure surface temperature: T_{wall}, cabin wall temperature with shirt-sleeve mode or T_{IS}, suit interior wall temperature for suited modes.

and T_{ug} and T_{enc} are in °F. The interchange factor depends upon the system geometry and surface coatings. The interchange factor is discussed subsequently in Section 3.4, Modes of Operation.

- Latent Heat Transfer, q_{lat}
  Latent Heat Transfer (q_{lat}) consists of diffusion of water vapor from the skin (q_{dif}) and evaporation of sweat (q_{swt}). Normally, under comfortable conditions, a rather nominal quantity of water leaves the skin surface by simple gaseous diffusion. The body consists mostly of water, and therefore the partial pressure of water at the surface of the skin is usually greater than the partial pressure of water in the surrounding atmosphere, which results in diffusion (the equation is given in Section 3.4, Modes of Operation.)

  However, if the metabolic rate, and consequently heat generation, is increased due to heavy workloads, etc., sensible convection, radiation, and diffusion may not be enough to dissipate the excessive production of heat. If this occurs, body temperatures begin to rise. If these temperatures increase appreciably above their set point or normal values, sweat glands secrete excessive water onto the skin surface. The sweat on the surface of the skin will then absorb heat as it evaporates. The production of sweat is the most significant and controllable element that the human thermoregulatory system has at its disposal.

  The model calculates q_{swt} for each skin compartment. Sweat production depends on the temperature difference of critical body temperatures from their normal values. A more detailed evaluation is given in Section 3.3, Active Controllers. As long as the environment, suited or shirt-sleeve, remains within certain bounds, all of the sweat on the skin compartment surface will be evaporated. However, if the environment is such that the maximum amount of sweat that can be evaporated (E_{max}) is less than the amount being produced (q_{swt}), then the body will not be able to dissipate the difference, and consequently, will store heat. This maximum evaporative capacity, E_{max}, is determined for each segment as:

$$E_{max} = \bar{h}_{D,j} A_C V_{effm} \frac{h_{fg}}{R\, T_{gas}} (P_{T_{ug}} - P_{T_{dew}}) \qquad \text{(Btu/hr)}$$

where $\bar{h}_{D,j}$ is the mean mass transfer coefficient (ft/hr), A_C is the convective area of the skin, h_{fg} is the enthalpy of vaporization, V_{effm} is the ventilation efficiency (compensates for errors inherent in using mean mass transfer coefficients), R is the gas constant, and T_{gas} is the temperature of the gas, and $P_{T_{ug}}$ and $P_{T_{dew}}$ are partial water vapor pressures evaluated at

T_{ug} and the dew point, respectively. The evaluation of $\bar{h}_{D,j}$ is discussed further in Section 3.4, Modes of Operation.

- Undergarment Heat Transfer, q_{ug}
  The model accounts for sensible heat which passes through an undergarment (q_{ug}). That is, in both the shirt-sleeve and suited modes, the undergarment temperature is determined by balancing the conduction heat transferred from the skin to the undergarment with the convection and radiation heat transfer away from the undergarment. Specifically, for each skin compartment covered by the garment:

$$q_{ug} = K_{ug} (T_s - T_{ug}) = q_{senc} + q_{rad} \qquad \text{(Btu/hr)}$$

where K_{ug} is the undergarment conductance. For those skin compartments covered by the undergarment, heat and mass transfer occurs from the undergarment to the gas stream or wall. For those skin compartments not covered by the undergarment (head, hands, and feet), heat and mass transfer occurs from the skin directly to the gas stream or wall.

- Heat Transfer to the LCG, q_{lcg}
  The LCG was developed to remove excessive heat generated during high workloads. The garment utilizes cool water through a network of small tubes covering the skin to absorb heat and to avoid or reduce heat storage. The current LCG covers only the trunk, arms, and legs, and is split up in the model on a percentage water flow basis. LCG utilization is optional in shirt-sleeve or suited operation. During EVA, this mode of heat removal is the most significant. The LCG heat removal (q_{lcg}) is the heat transfer to the coolant from each body segment:

$$q_{lcg} = f\, \dot{m}_{lcg}\, c_{p_w} (T_{outlet} - T_{inlet}) \quad \text{(Btu/hr)}$$

where

f = percent of flow of coolant in LCG to each body segment

$\dot{m}_{lcg}$ = LCG water flow rate, lbm/hr
c_{p_w} = specific heat of coolant (=1 for water), Btu/lb °F
T_{inlet} = temperature of the coolant at the LCG inlet

T_{outlet} = temperature of the coolant at the LCG outlet

The temperature difference of the LCG coolant is determined from an empirical expression:

$$(T_{outlet} - T_{inlet}) = (1.0 - e^{-\eta})\,(T_{av} - T_{inlet})$$

where

T_{av} = weighted average of the skin temperatures of the trunk, arms and legs

$$\eta = \frac{UA}{\dot{m}_{lcg}\, c_{p_w}}$$

and UA is the overall heat transfer coefficient between the skin and the LCG [4]. The UA is an empirically determined function of the total latent heat including sweat run-off (see Appendix E). Thus, the $(1.0 - e^{-\eta})$ term is the LCG effectiveness:

$$(1.0 - e^{-\eta}) = \frac{T_{outlet} - T_{inlet}}{T_{av} - T_{inlet}}$$

3.2.4 Respiratory Heat Transfer

In addition to those modes of heat transfer from the skin surface to the surroundings, there are two other pathways, respiratory sensible and respiratory latent heat transfer. Generally, the respiratory tract and lungs do not account for much heat removal; however, at high metabolic rates, they may contribute significantly toward maintaining stable body temperatures.

- Respiratory Sensible Heat Transfer, q_{rsen}

  As cool gas enters the respiratory tract and flows into the lungs it is warmed to body temperature by convection. This sensible respiratory convection (q_{rsen}) is determined from an empirical equation [5]:

$$q_{rsen} = q_{met}\, c_{pg} \left[\frac{0.0418\,(144.0\, P_g)}{48.3\,(T_g + 460)}\right] (T_r - T_g) \qquad \text{(Btu/hr)}$$

where c_{pg}, P_g and T_g are the specific heat, pressure and temperature of the inspired gas, respectively, which take the values of the cabin gas in the shirt-sleeve and helmet-off modes. Otherwise, the helmet gas properties are used. The variable T_r, is the respiratory temperature, a weighted average of the head and trunk compartments containing the respiratory tract and lungs:

$$T_r = (0.385\, T_c + 0.086\, T_m + 0.0287\, T_f)_{head} + (0.238\, T_c + 0.2615\, T_m)_{trunk} \qquad (\,^\circ F)$$

- Respiratory Latent Loss, q_{rlat}
  As relatively dry gas flows over the moist surfaces of the respiratory tract and the lung surfactant, water evaporates, humidifying the inspired air and cooling the body. The evaporative mass transfer through the respiratory tract and lungs is also determined from an empirical equation [5]:

$$q_{rlat} = q_{met}\left[\frac{0.0418\,(144.0\,P_g)}{48.3\,(T_g + 460)}\right]\left[\frac{18.0\,(1040.0)}{32.0\,P_g}\right](P_{T_r} - 0.8P_{av}) \quad \text{(Btu/hr)}$$

  where P_{T_r} is the water vapor pressure at the respiratory temperature, and P_{av} is the water vapor pressure of the cabin gas in shirt-sleeve or helmet-off modes, or the average of the inlet and outlet water vapor pressures of the helmet in the fully suited mode. The maximum evaporative capacity, E_{max} is compared to q_{lat}. Whichever is less is added to q_{rlat} to obtain the outlet water vapor pressure of the helmet.

- Heat Storage Rate, q_{storat}
  The instantaneous thermal disposition of the human body is evaluated by performing a heat balance on the overall system:

$$q_{storat} = q_{met} - (q_{lat} + q_{rlat} + q_{rsen} + q_{rad} + q_{lcg} + q_{senc} + U_{mech}) \quad \text{(Btu/hr)}$$

  If q_{storat} is positive, the net, cumulative, instantaneous heat transfer is from the environment to the body. If q_{storat} is negative, the net heat transfer is from the body to the environment. The storage rate is not to be used as a physiological guide for the crew's condition, but only as a means of monitoring the instantaneous direction of heat transfer. When q_{storat} approaches and levels near zero, the crew member is assumed to have reached steady-state conditions.

- Stored Heat, Q_{stor}
  Heat produced in excess of that which can be dissipated will be stored in the tissues with a resulting rise in body temperature. Heat storage (Q_{stor}) is calculated according to:

$$Q_{stor} = \sum_{i=1}^{40} C_i \left(T_i - T_{set,i}\right) \qquad \text{(Btu)}$$

where C_i is the heat capacitance of each body compartment (see Appendix F for detailed calculation), T_i is the body compartment temperature, and $T_{set,i}$ is the set point or normal body compartment temperature defined in Table 3.2. Note that these set point values are determined for the compartment nodes; therefore, skin node

Table 3.2
Set Point Temperatures of Body Compartments (°F)

Body Segments	Core	Muscle	Fat	Skin
Trunk	98.8	98.3	95.9	94.4
Arms	96.1	95.1	94.1	93.7
Legs	97.6	96.5	95.1	94.5
Hands	95.9	95.7	95.6	95.5
Feet	95.8	95.5	95.7	95.5
Head	98.6	97.6	97.0	96.6
	Central Blood	98.5		

temperatures will be higher than skin surface temperatures of typical physiological experiments. Values of Q_{stor} in excess of 300 Btu suggest an interruption of normal performance. That is, normal crew performance is likely to be impaired. Values of Q_{stor} in excess of 400 Btu are equivalent to high body temperature or moderate fever, with a distinct possibility of collapse. If Q_{stor} exceeds 750 Btu, the deterioration of life function is advanced, frequently with fatal results.

3.3 ACTIVE CONTROLLERS

The body has four primary controllers for maintaining itself in an essentially isothermal state. The primary controllers are:

1) Sweat production
2) Shivering
3) Vasodilation
4) Vasoconstriction

The equations describing active human thermoregulatory control rely heavily on experimental findings.

3.3.1 Heat Removal by Sweating, qswt

Active sweating is initiated when all other mechanisms of heat removal are insufficient for dissipating metabolic heat production. As body temperatures rise and heat storage increases, temperature sensors in the skin and the hypothalamic region of the brain detect deviations and activate the sweat glands. The brain integrates these temperature signals and acts as a central controller of the sweat response. The equation describing the control of sweat is a function of the positive deviation of the head core and skin compartment temperatures from their normal or set point values [2]:

$$S = (T_c - T_{set,c})_{head}\left\{884.0 + 73.4\left[\sum_s K_s\,(T_s - T_{set,s})\right]\right\} \qquad \text{(Btu/hr)}$$

where S is the sweat signal, $_s$ denotes the summation of all skin compartments, $T_{set,s}$ is the set point temperature for each skin compartment defined above in Table 3.2, and K_s represents distribution coefficients based on the weighted mass of each skin compartment and presented in Table 3.3. Negative skin temperature deviations are set to zero as cooler than normal skin compartments do not contribute positively or negatively to the sweat signal. However, if the head core (hypothalamic) temperature deviation from set point is less than or equal to zero, sweat production is zero.

The sweat signal is distributed to the skin compartments, but actual sweat production of a given skin compartment, $q_{swt,s}$, is also influenced by local skin temperature:

$$q_{swt,s} = S\,K_s^{'}\,2.0^{\left(\frac{T_s - T_{set,s}}{7.2}\right)} \qquad \text{(Btu/hr)}$$

where $K_s^{'}$ is the sweat distribution coefficient defined in Table 3.3. The exponential term accounts for the local skin temperature effect, that is, local sweating doubles or halves, respectively, for a positive or negative local skin temperature deviation of 7.2 °F from the set point temperature [2]. The total sweat production, q_{swt}, is the sum of the

sweat produced by all skin compartments, $_s(q_{swt,s})$.

Table 3.3
Skin Compartment Distribution Coefficients
for Mass, K_S
and Sweat Production, $K_S^{'}$

	K_s	$K_s^{'}$
Trunk	0.5870	0.482
Arms	0.0822	0.153
Legs	0.1860	0.218
Hands	0.0222	0.031
Feet	0.0399	0.035
Head	0.0827	0.081
	1.0000	1.000

3.3.2 Heat Production by Shivering, q_{shiv}

Active shivering has the opposite effect of sweating. The body shivers to effectively increase the metabolic rate in order to compensate for excessive heat loss:

$$q_{shiv} = 12.22\,(T_{set,c} - T_c)_{head}\left[\sum_s K_s(T_{set,s} - T_s)\right] \qquad \text{(Btu/hr)}$$

where, again, $_s$ is the summation of all skin compartments and K_s is the skin compartment mass distribution coefficient defined in Table 3.3. Negative values for shiver are not allowed; if, for a given segment, the skin temperature exceeds the set point temperature, then $K_s(T_{set,s} - T_s)$ is set to zero. Shiver is distributed to the muscle nodes:

$$q_{mshiv} = K_{ms}\, q_{shiv} \qquad \text{(Btu/hr)}$$

where K_{ms} is presented in Table 3.4. The q_{mshiv} term is added to the q_{met} of each muscle compartment.

3.3.3 Blood Flow, $\dot{m}$

In nominal conditions, all tissue compartments have specific basal blood flows ($\dot{m}_{basal,i}$). These are presented in Table 3.5. However, when the body is subjected to thermal stress or exercise, the total blood flow to individual body compartments ($\dot{m}_i$), can increase or decrease from the basal level. The resulting changes in the intrinsic convection can affect body compartment temperature and overall heat transfer rate. What follows is a description of how blood flow changes are modeled for each body compartment.

- Blood Flow Equations for the Core and Fat Nodes
  The basal blood flows in the core and fat nodes are largely unaffected by moderate thermal stresses or exercise. Therefore:

$$\dot{m}_c = \dot{m}_{basal,c} \qquad \text{(lbm/hr)}$$

$$\dot{m}_f = \dot{m}_{basal,f} \qquad \text{(lbm/hr)}$$

- Blood Flow Equation for the Muscle Nodes
  As the muscles perform work aerobically, the oxygen requirements are proportional to the work rate. For every increase in work rate of 1 Btu/hr an increase of oxygen

Table 3.4
Distribution Coefficient, Kms, of qshiv to the Muscle Compartments

Muscle Compartment	K_{ms}
Trunk	0.9480
Arms	0.0053
Legs	0.0190
Hands	0.0023
Feet	0.0024
Head	0.0230
	1.0000

Table 3.5

Basal Blood Flow, $\dot{m}_{basal,i}$ (lbm/hr)

Body Segments	Core	Muscle	Fat	Skin
Trunk	510.000	14.080	5.060	4.620
Arms	1.518	2.728	0.704	1.100
Legs	4.640	8.140	1.760	6.270
Hands	0.220	0.110	0.110	4.400
Feet	0.330	0.066	0.176	6.600
Head	105.600	0.596	0.264	3.700

uptake by the muscles of about 3.07 in^3 (standard temperature and pressure) is required. To supply this oxygen to the muscles an increase in the blood flow of 0.554 lbm/hr is required. Thus:

$$\dot{m}_m = \dot{m}_{basal,m} + 0.554\,(q_{met,m} - q_{BMR,m}) \qquad \text{(lbm/hr)}$$

- Blood Flow Equation for the Skin Nodes
  The control of blood flow to the skin through vasodilation and vasoconstriction is an important thermal regulator. The resulting changes in $q_{conv,s}$ are particularly significant to the overall heat transfer rate because the skin nodes are directly exposed to the environment. Because the intrinsic convection also affects skin temperatures, vasodilation and vasoconstriction can influence sweating and shivering rates.

Vasodilation ($\dot{m}_{dilate}$) is the controlled enlargement or dilation of arteries and arterioles, the vessels which carry blood to the tissues. In a hot environment, the blood vessels supplying the skin are dilated to increase the blood flow to the skin compartments so that more heat is carried away from the muscle and core compartments. This increase has the effect of maintaining stable deep body temperatures while elevating skin temperatures and enhancing heat transfer at the skin surface. Vasodilation has been empirically determined to be strongly dependent on positive deviations from the head core temperature from set-point [2]:

$$\dot{m}_{\text{dilate}} = 183.5\,(T_c - T_{set,c})_{head} \qquad \text{(lbm/hr)}$$

Vasodilation is modeled as a source term, added to the basal blood flow. If, for a particular segment, the core temperature is lower than the core set-point temperature, then the vasodilation signal is zero.

Vasoconstriction is the controlled constriction of blood vessels to the skin compartments to conserve heat in the critical head and trunk core regions. In a cold environment, the body attempts to maintain normal core temperatures in the head and trunk at the expense of all other regions. Unlike vasodilation, the vasoconstriction mechanism can be elicited in the absence of a head-core signal. The assumption is that the body would like to prevent shivering at all costs. Thus, blood flows to all muscle and skin compartments are restricted in an attempt to maintain an isothermal head core temperature and avoid shivering. Vasoconstriction is modeled as a dimensionless factor ($\mathcal{R}$), the sum of the arterial resistance [2]:

$$R = 5.55\left\{ (T_{set,c} - T_c)_{head} + \left[\sum_s K_s (T_{set,s} - T_s) \right] \right\}$$

where K_s values are defined above in Table 3.3. As with vasodilation, if the temperature differential of the head core or any skin node is negative, then it is set to zero.

Thus, the controlling equation for blood flow rates to the skin nodes is [2]:

$$\dot{m}_s = \frac{\dot{m}_{basal,s} + K_{dil}\,\dot{m}_{dilate}}{1.0 + K_{con}\,\mathcal{R}} \qquad \text{(lbm/hr)}$$

where K_{dil} and K_{con} are the distribution coefficients for vasodilation and vasoconstriction, respectively, defined in Table 3.6.

Table 3.6
Coefficients for the Distribution of Vasodilation, K_{dil}, and Vasoconstriction, K_{con}, to the Skin Nodes

Body Segments	K_{dil}	K_{con}
Trunk	0.322	0.15
Arms	0.095	0.05
Legs	0.230	0.05
Hands	0.122	0.35
Feet	0.100	0.35
Head	0.132	0.05
	1.001	1.00

3.4 MODES OF OPERATION

In this section the basic equations presented in Sections 3.2 and 3.3 are developed further, in particular, where different relationships exist for specific variables among the four operational modes . Also, equations relating to convection and radiation with the outside suit surface, and to the postlanding option, are introduced.

3.4.1 Shirt-Sleeve Mode

Shirt-sleeve mode models a man in a cabin, or in any environment, wearing an undergarment. The undergarment covers the trunk, arms and legs and can be given insulation values to simulate various thicknesses of clothing. The heat-transfer paths are shown schematically in Figure 3.5. The cabin or environmental conditions are constant. For the shirt-sleeve mode, the human thermal environment is strictly input. The man model is broken up into the usual number of body compartments, with each seeing the same environment, rather than a different environment for each body segment as is the case of the suited modes.

- Extrinsic Convection Equations
  The convective heat transfer for each skin compartment in the shirt-sleeve environment is calculated from:

$$q_{senc} = 0.0212\,(P_{cab}\,V_{cab})^{1/2}\,\kappa_1\,A_C\,(T_{ug} - T_{cab}) \quad \text{(Btu/hr)}$$

for forced convection [6], and

$$q_{senc} = 0.06\left[G\,(P_{cab})^2\,|T_{ug} - T_{cab}|\right]^{1/4}\kappa_2\,A_C\,(T_{ug} - T_{cab}) \quad \text{(Btu/hr)}$$

for free convection [6], where G is the ratio of actual to terrestrial gravity fields (local acceleration divided by 32.2 ft/s2), □1 and □2 are coefficients to account for the segment size of each subject, AC is the convective area of each skin node, and Pcab, Vcab, and Tcab are the pressure, velocity and temperature of the surrounding gas stream, respectively. For the shirt-sleeve mode, the variable Tug is the undergarment temperature for the trunk, arm, and leg segments, and the skin temperature for the rest of the segments, i.e. those not covered by the undergarment. Both of these expressions are derived from an analysis of flow perpendicular to a vertical cylinder. Expressions resulting from evaluation of flow parallel to a flat plate are not appreciably

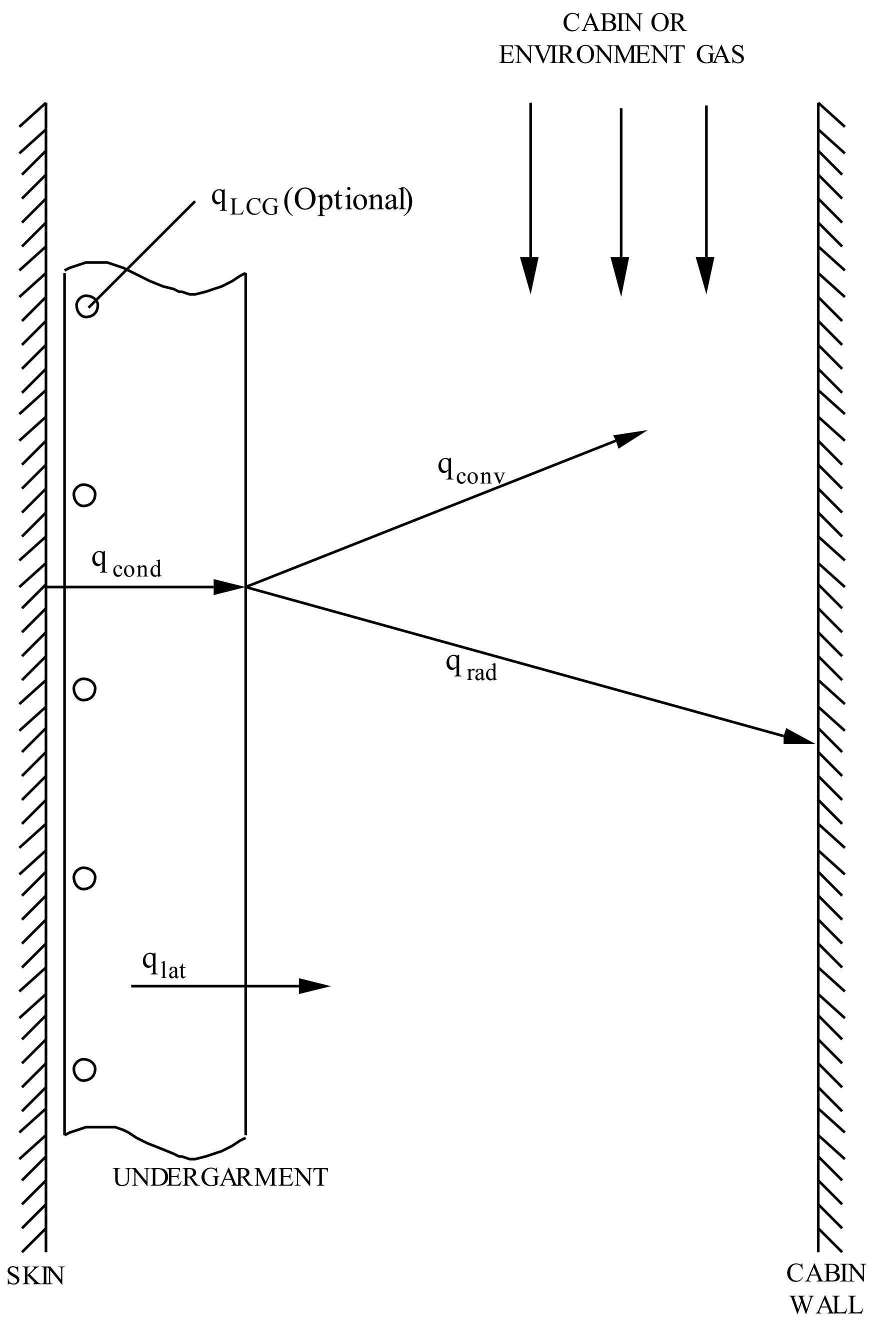


Figure 3.5 Shirt-Sleeve Mode Heat Transfer Paths

different. In weightless environments free convection does not exist. However, for environments in a gravity field (G > 0), the larger of the forced or free convection coefficients is used to predict q_{senc}. For derivations of these relations see Appendix G.

- Skin Diffusion

Loss of moisture from the skin by diffusion is [7]:

$$q_{dif} = 6.66\, A_C\, (P_{Tug} - P_{Tdew}) \qquad \text{(Btu/hr)}$$

Diffusion loss is typically small.

- Maximum Evaporative Capacity
  In the shirt-sleeve mode, the maximum evaporative capacity (E_{max}) is calculated for each skin compartment from:

$$E_{max} = 0.126\, \kappa_1\, A_C\, V_{effm} \left(\frac{V_{cab}}{P_{cab}}\right)^{1/2} (T_{cab} + 460)^{1.04} (P_{Tug} - P_{Tdew}) \qquad \text{(Btu/hr)}$$

for forced convection conditions [6], and

$$E_{max} = 1.32\, \kappa_2\, A_C\, V_{effm}\, \frac{T_{cab} + 460}{P_{cab}} \{P_{cab}\, G\, |0.005\, P_{cab}\, (T_{ug} - T_{cab})$$
$$+ 1.02\, (P_{Tug} - P_{Tdew})|\}^{0.25} (P_{Tug} - P_{Tdew}) \quad \text{(Btu/hr)}$$

for free convection conditions [6], where κ_1 and κ_2 are coefficients to adjust segment size according to the subject's size, V_{effm} is the ventilation efficiency, and $(P_{Tug} - P_{Tdew})$ is the difference of the water vapor pressure at skin surface and the environment. Both of these expressions are derived in Appendix H by applying the heat-mass transfer analogy to the vertical cylinder model discussed previously. Again, for environments in a gravity field ($G > 0$), the larger of the free and forced mass transfer coefficients is utilized to calculate E_{max}. The model also accounts for conditions in which q_{lat} is greater than E_{max}. When this occurs, the excess latent heat is presented as sweat run-off. The ventilation efficiency compensates for errors of using mean mass transfer coefficients to account for evaporation on a vertical cylinder in forced convection conditions [8], and is applied to all suited modes as well (see Appendix I for a more detailed description).

- Radiation Heat Transfer
  The equation for radiation heat transfer, repeated for convenience, for each skin compartment is calculated as:

$$q_{rad} = A_R\, \sigma\, \mathcal{F} [(T_{ug} + 460.0)^4 - (T_{wall} + 460.0)^4] \qquad \text{(Btu/hr)}$$

In the shirt-sleeve mode the interchange factor, $\mathcal{F}$ is:

$$\mathcal{F} = \varepsilon_{ug}\, F$$

where ε_{ug} is the undergarment emissivity and F is the view factor of the body to the cabin or enclosure walls. This expression is derived from an analysis of one grey body completely enclosing another with an enclosing surface area (wall) much larger than the enclosed surface area (man). The incident solar radiation on a subject working or exercising outdoors can also be determined (see Section 5.3.5).

3.4.2 Suited Modes

The space suit is treated in much the same manner as the man. That is, it is divided into segments with one suit segment for each body segment (see Figure 3.6.).

There are several modes of space suit operation that are considered. The modes are:

1) EVA
2) IVA
3) Helmet off
4) Purge flow

The EVA mode is utilized during extravehicular activity. Suit inlet gas from the applicable environmental control system (currently, the PLSS) enters the suit, and is diverted to the helmet through a duct. The flow then passes to the trunk area, and is then split with 75 percent of the gas going to the arms and hands, and 25 percent going to the legs and feet where it is collected in ducts, and passed out of the suit. The flow paths are shown in Figure 3.7.

The IVA, or intravehicular mode, follows the same path as the EVA mode, except the flow is initially split between the helmet and the trunk as it enters the suit. All the flow entering the helmet flows into the trunk. The arms and hands receive 60 percent of the total flow, while the legs and feet receive 40 percent. The flow path is shown schematically in Figure 3.8.

The helmet-off mode is shown in Figure 3.9. The flow is reversed so that it is directed into the ducts, over the extremities, and out of the helmet neck ring.

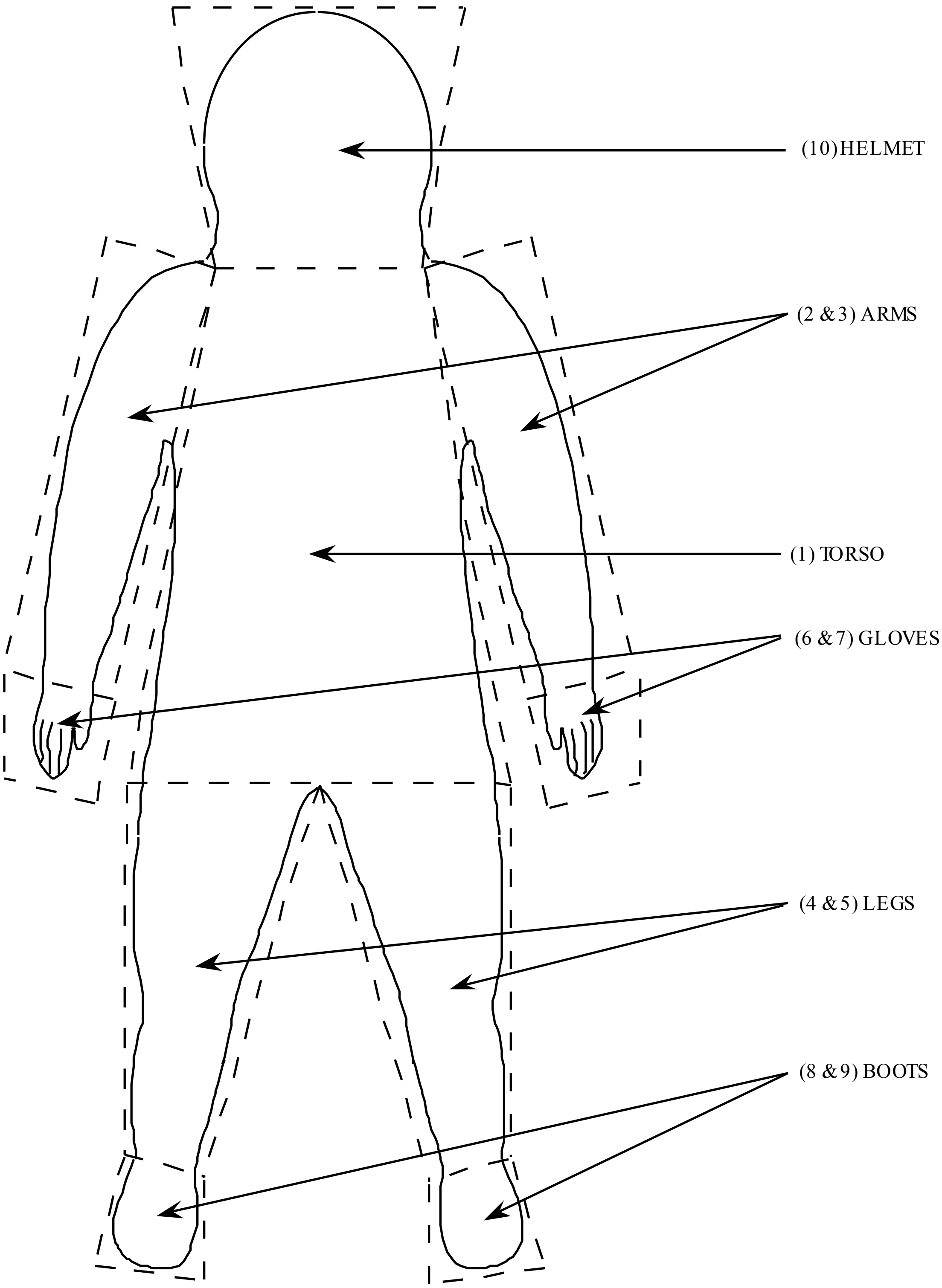


Figure 3.6 Ten Segments of the Suit

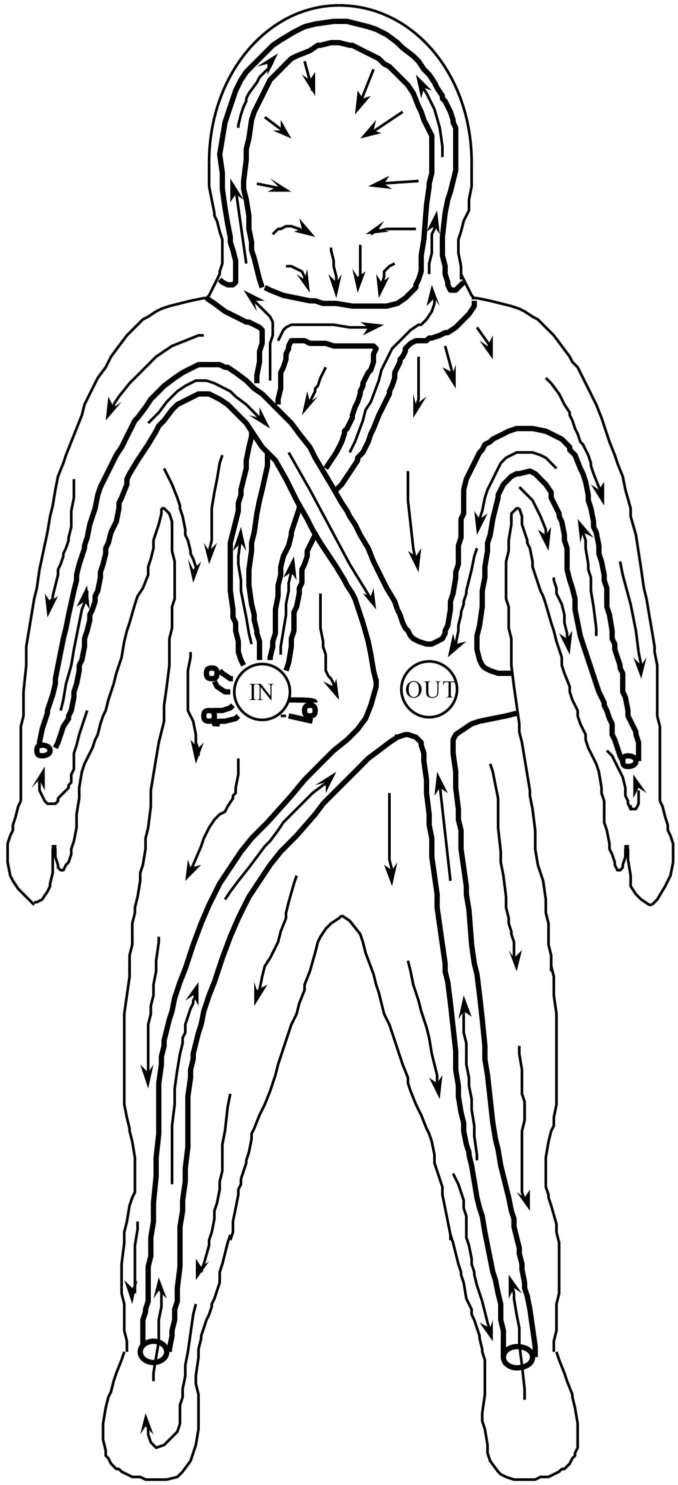


Figure 3.7 Suit Ventilation for Extravehicular Operation

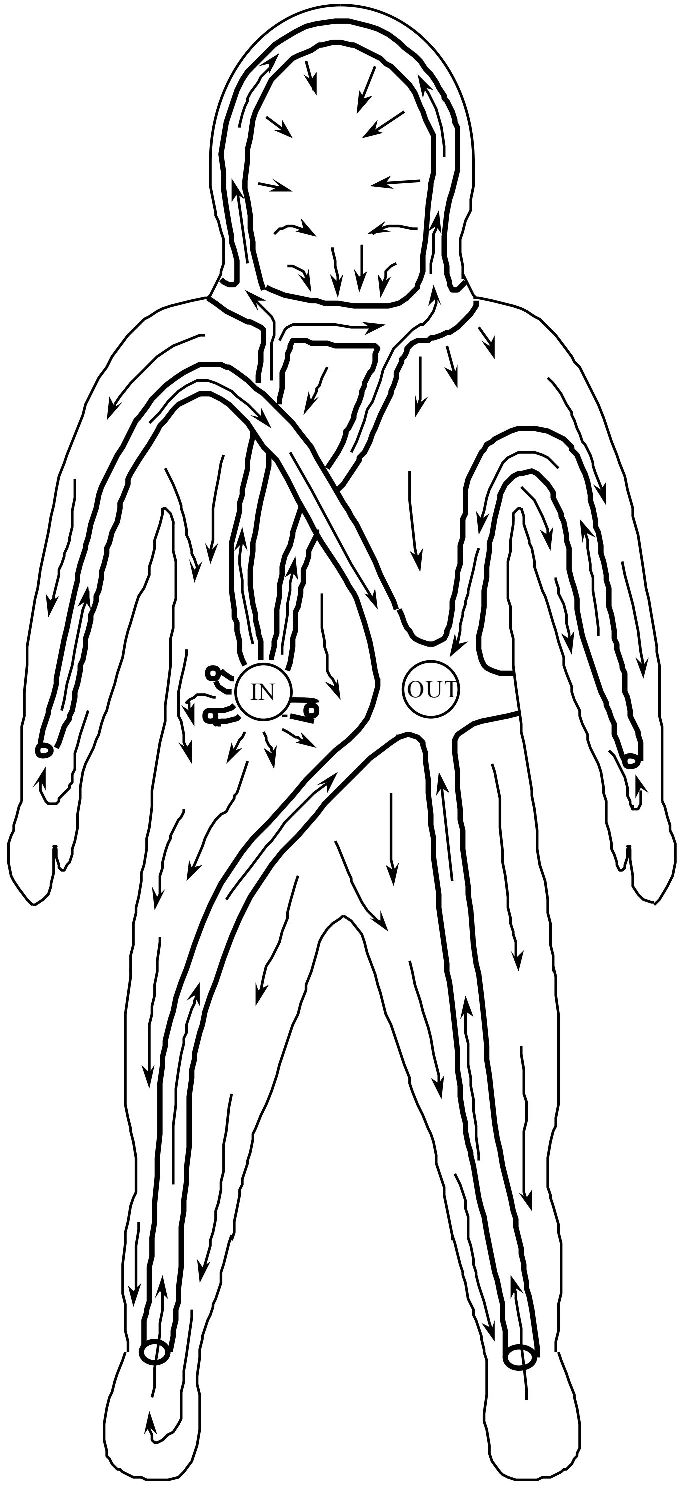


Figure 3.8 Suit Ventilation for Intravehicular Operation

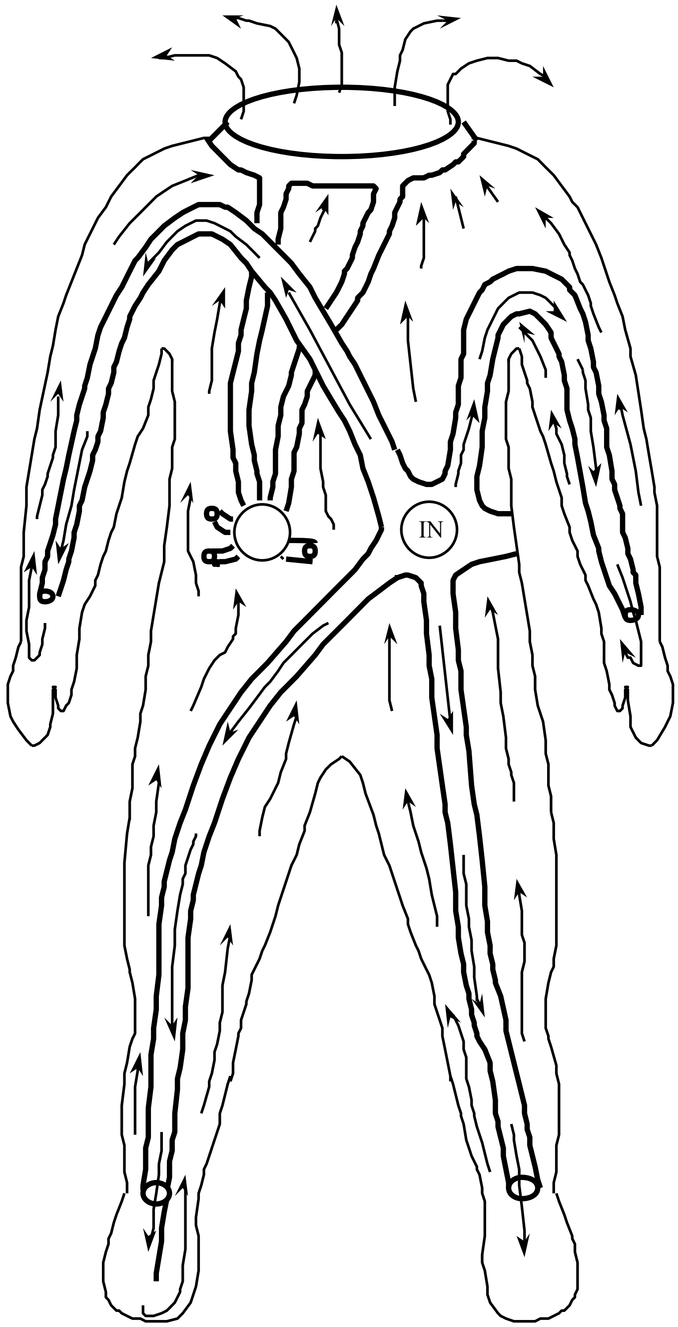


Figure 3.9 Suit Ventilation with Helmet Off

The purge flow operation is utilized when dry ventilation gas enters the suit, and is not to be recirculated. The purge option can be used with any of the three-suited modes.

The heat-transfer paths for a suited crew member are considerably more complex than those for a shirt-sleeve crew member. They are shown schematically in Figure 3.10. The suit inlet conditions are constant, or may be read in from a table. For the suited mode, the thermal environment is calculated, based on suit inlet conditions and the particular crew tasks being considered. That is, the inlet conditions for each suit segment depend upon the outlet conditions from the previous body compartment in the appropriate flow path.

- Extrinsic Convection
  For each skin compartment the sensible convection in the suit environment is calculated from:

$$q_{senc} = 0.134 \ (\dot{m}_{gas})^{1/3} \kappa_3 A_C (T_{ug} - \bar{T}_{gas}) \text{ (Btu/hr)}$$

where κ_3 is a correction factor to account for the segment size of the subject, and $\dot{m}_{gas}$ is the mass flow rate of the gas in each segment. The quantity $0.134 \ (\dot{m}_{gas})^{1/3}$ is the average heat transfer coefficient, $\bar{h}$, derived by considering the flow through a duct. This consideration yields results that correspond well with test data [6]. The log mean gas temperature, $\bar{T}_{gas}$, is calculated for each suit segment by considering the heat transfer from two flat surfaces, the suit interior and the skin, to an elemental volume of flowing gas. Specifically:

$$\bar{T}_{gas} = T_{av} - \alpha \left(1 - e^{-1/\alpha}\right) \left(T_{av} - T_{gas_{in}}\right) \ (\text{°F})$$

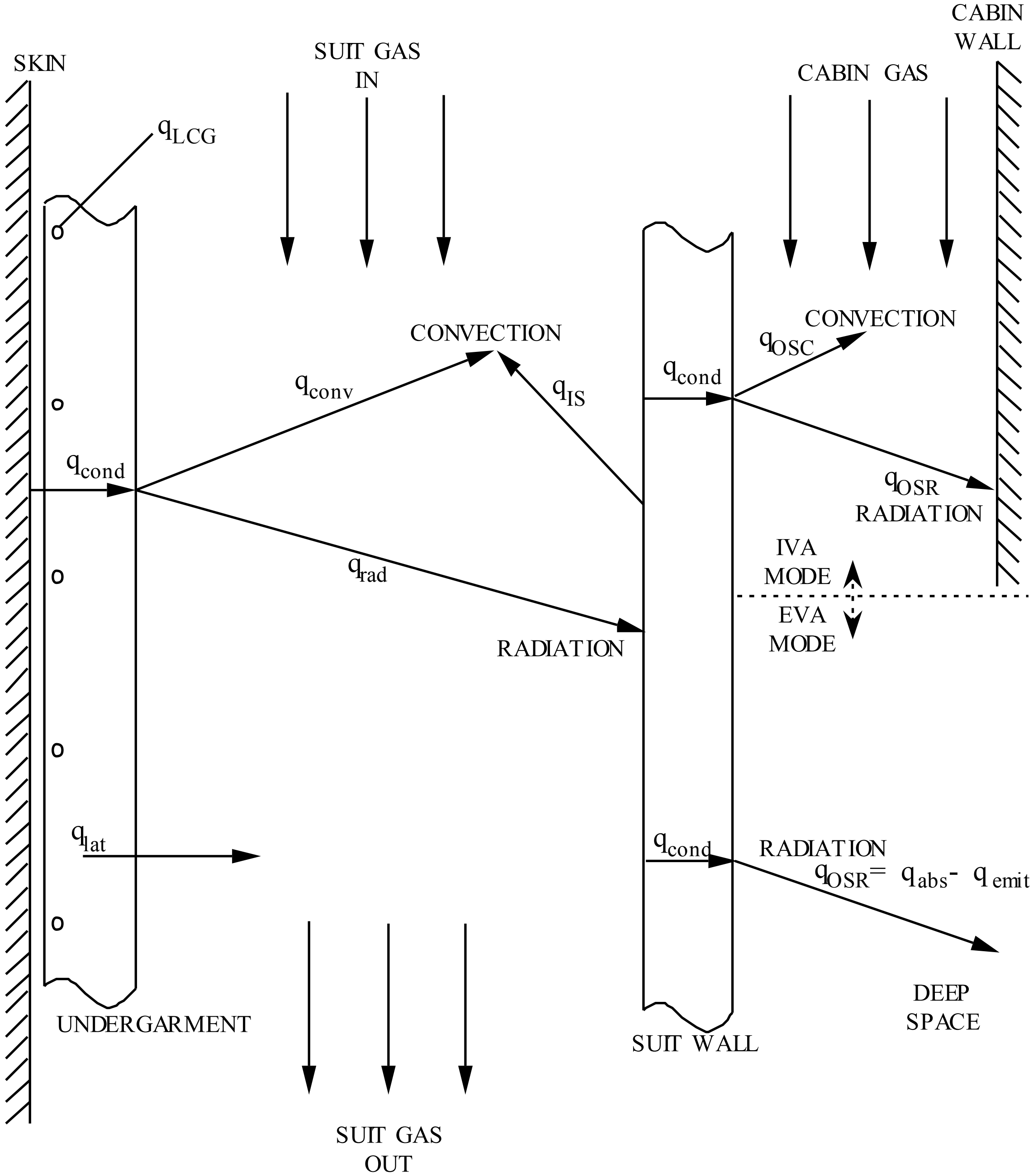


Figure 3.10 Heat Transfer Paths for Suited Modes

and

$$\alpha = \frac{\dot{m}_{gas}\, c_{p_g}}{2\, \bar{h}\, \kappa_3\, A_C}$$

where for a particular suit segment, $T_{gas_{in}}$ is the gas temperature into the segment, and T_{av} is the average of the temperature of the inside suit surface and that of the undergarment or skin

$$T_{av} = \frac{T_{IS} + T_{ug}}{2} \quad (\,°F)$$

The outlet gas temperature for each suit segment, $T_{gas_{out}}$, is a function of the convection with the man, q_{senc}, and the convection heat transfer from the inside suit surface to the gas stream, q_{IS}. Accordingly, we can write for each suit segment:

$$\dot{m}_{gas}\, c_{p_g} (T_{gas_{out}} - T_{gas_{in}}) = q_{senc} + q_{IS}$$

where

$$q_{IS} = 0.134\, \kappa_3\, A_C\, (\dot{m}_{gas})^{1/3}\, (T_{IS} - \overline{T}_{gas})$$

For each suit segment, this expression is solved for $T_{gas_{out}}$, and the result, in turn, is set equal to the gas stream inlet temperature, $T_{gas_{in}}$, for the next suit segment in the appropriate gas flow path.

In the case of a suited man in a ventilated environment, the convection with the suit outer surface, q_{OSC}, is similar to that of the shirt-sleeve mode:

$$q_{OSC} = 0.0212\, \kappa_4\, A_{OS}\, (P_{cab}\, V_{cab})^{1/2}\, (T_{OS} - T_{cab})\, \text{(Btu/hr)}$$

for forced convection and

$$q_{OSC} = 0.06\, \kappa_2\, A_{OS} \left[G\, (P_{cab})^2\, |T_{OS} - T_{cab}| \right]^{1/4} (T_{OS} - T_{cab}) \qquad \text{(Btu/hr)}$$

where A_{OS} and T_{OS} are the area and temperature of the outside suit surface and κ_2 and κ_4 adjusts the suit segment dimensions for body size.

- Skin Diffusion
  The same relation is used to calculate the q_{dif} for the suit mode as in the shirt-sleeve mode , except that the log mean pressure difference is used [7]:

$$q_{dif} = 6.66\, Ac\, \frac{(P_{out} - P_{in})}{\ln\left(\dfrac{P_{ug} - P_{in}}{P_{ug} - P_{out}}\right)} \qquad \text{(Btu/hr)}$$

where P_{out}, P_{in} and P_{ug} are the outlet, inlet and skin/undergarment water vapor pressures of each suit segment, respectively.

- Maximum Evaporative Capacity

  The maximum evaporative heat capacity for the suited mode, E_{max}, is calculated for each skin compartment by:

$$E_{max} = 1040.0\ V_{effm}\ \dot{m}_{gas} \left[\frac{18.0\ (P_{out} - P_{in})}{\mathcal{M}_{gas}\ P_{gas}} \right] \quad \text{(Btu/hr)}$$

where 1040.0 (Btu/lbm) is the heat of vaporization for water at 95 °F, P_{out} is the maximum water vapor partial pressure at the outlet of each suit segment (limited by mass transfer and saturation) and P_{in} is the water vapor partial pressure of the inlet to each suit segment (in psia), and $\mathcal{M}_{gas}$ is the average molecular weight of the gas. The term in the brackets "[ ]" is the mass ratio of the water vapor to the suit gas.

The maximum water vapor partial pressure outlet for each suit segment, P_{out}, is equal to the inlet partial pressure plus the maximum quantity of water evaporated into the gas stream. The pertinent equation for convection mass transfer is a complex logarithmic expression that considers mass transfer from an elemental area of one surface (skin or undergarment) to a flowing gas (for the derivation see Appendix H.2). Specifically, for each segment:

$$P_{out} = P_{in} + (P_{ug} - P_{in})\ (1 - e^{\beta}) \quad \text{(psia)}$$

and

$$\beta = \left[\frac{144.0\ P_{gas}\ A_C\ \bar{h}_{D,j}}{R\ \dot{m}_{gas}\ (T_{gas_{in}} + 460.0)} \right]$$

where $T_{gas_{in}}$ is inlet gas temperature to each segment and $\bar{h}_{D,j}$ is the average mass transfer coefficient for each segment

$$\bar{h}_{D,j} = \kappa_3 \frac{0.00866\ \dot{m}_{gas}^{1/3}\ (T_{gas_{in}} + 460.0)^{1.53}}{P_{gas}} \quad \text{(ft/hr)}$$

The mass transfer coefficient is calculated by applying the heat-mass transfer analogy to the heat transfer expression for flow through a duct [6]. Again, this gives reasonable agreement with test data. The mass transfer is considered to result from the differential between the water vapor pressure evaluated at skin temperature and a log mean gas stream partial pressure (see Appendix H.2.1), derived in much the same manner as the log mean gas temperature described previously. As in the heat transfer analysis, the gas flow path of the appropriate suited mode is utilized. The outlet partial pressure of one suit segment is equated to the inlet partial pressure of the next suit segment in the flow path. However, to determine the actual partial pressure in each suit segment (versus the maximum), the calculated value of E_{max} is compared with q_{lat}. The minimum of these two quantities is added to the inlet partial pressure and, for the helmet segment, to the partial pressure of the respiration, to determine the correct outlet partial pressure. Both skin diffusion and lung respiration also utilize the partial pressure calculations described above.

- Radiation Heat Transfer
  Radiation heat exchange between a skin compartment and the corresponding suit segment is calculated by:

$$q_{rad} = A_R \sigma \mathcal{F} [(T_{ug} + 460.0)^4 - (T_{IS} + 460.0)^4] \qquad \text{(Btu/hr)}$$

where $\mathcal{F}$ is the grey body interchange factor for concentric infinite cylinders (space suit surrounding a man):

$$\mathcal{F} = \frac{(\varepsilon_{ug}\, \varepsilon_{IS})}{\varepsilon_{IS} + \varepsilon_{ug} - (\varepsilon_{ug}\, \varepsilon_{IS})}$$

Radiation heat exchange between the outside suit surface and the environment, q_{OSR}, also affects the suited man. The appropriate equations for each segment are:

$$q_{OSR} = A_{OS} \sigma \mathcal{F} [(T_{OS} + 460.0)^4 - (T_{wall} + 460.0)^4] \qquad \text{(Btu/hr)}$$

for a suited crew member situated in an enclosed cabin, where $\mathcal{F} = \varepsilon_{OS}$ F, and

$$q_{OSR} = A_{OS} [\sigma\, \varepsilon_{OS} (T_{OS} + 460.0)^4 - q_{abs}] \qquad \text{(Btu/hr)}$$

for a lunar surface or EVA case where absorbed heat, q_{abs}, is known.

The radiation heat leak of the crew member to the inside suit surface is limited by the amount of radiation that can actually get through the suit and into the environment.
That is, the net radiation heat transfer from the man to the suit interior depends upon the suit interior surface temperature. This condition, in turn, depends upon the net heat leak through the suit. Consequently, we need to consider all factors affecting the suit interior surface temperature, that is radiation heat transfer with the inside and outside of the suit, q_{rad} and q_{OSR}, and convective heat transfer with the inside and outside of the suit, q_{IS} and q_{OSC}, and finally conduction through the suit. A heat balance is performed on the outer and inner suit surface utilizing these terms. The resulting equations permit computation of T_{IS} and q_{rad}. Specifically:

$$\frac{m_S\, c_{p_S}}{\Delta t} (T^{n}_{OS} - T^{n-1}_{OS}) = K_S A_S (T^{n-1}_{IS} - T^{n-1}_{OS}) - (q_{OSR} + q_{OSC})$$

and

$$\frac{m_S\, c_{p_S}}{\Delta t}\,(T_{IS}^{n} - T_{IS}^{n-1}) = q_{rad} - [q_{IS} + K_S\, A_S\,(T_{IS}^{n-1} - T_{OS}^{n-1})]$$

where K_S, A_S, m_S, and c_{p_S} are the conductance, area, weight and specific heat of the suit segment, respectively, Δt is the time step, and the superscripts n and n−1 refer to the previous and current time steps, respectively. The outer and inner surface temperatures of the suit are computed after each time step.

3.5 MISCELLANEOUS CALCULATIONS

The model determines the consumption of oxygen (O_2) and the production carbon dioxide (CO_2) of each crew member based on the metabolic rate and the respiratory quotient (the ratio of CO_2 produced to O_2 consumed). The model also has the capability of computing the carbon dioxide (CO_2) concentration in the suit helmet, and carbon dioxide, humidity, and temperature levels in a postlanding environment, that is a cabin or spacesuit purged with the surrounding atmosphere (see Figure 3.11). Carbon dioxide, water, and heat are generated by the crew into the cabin. Depending upon the flow through the closed environment all three waste products may build up. The humidity and temperature determinations in a space suit have already been described. The postlanding and helmet CO_2 analyses are presented below, along with their pertinent differential equations. As in all previous transient calculations, a forward difference procedure is used with the time increment Δt (see Section 5.3.10).

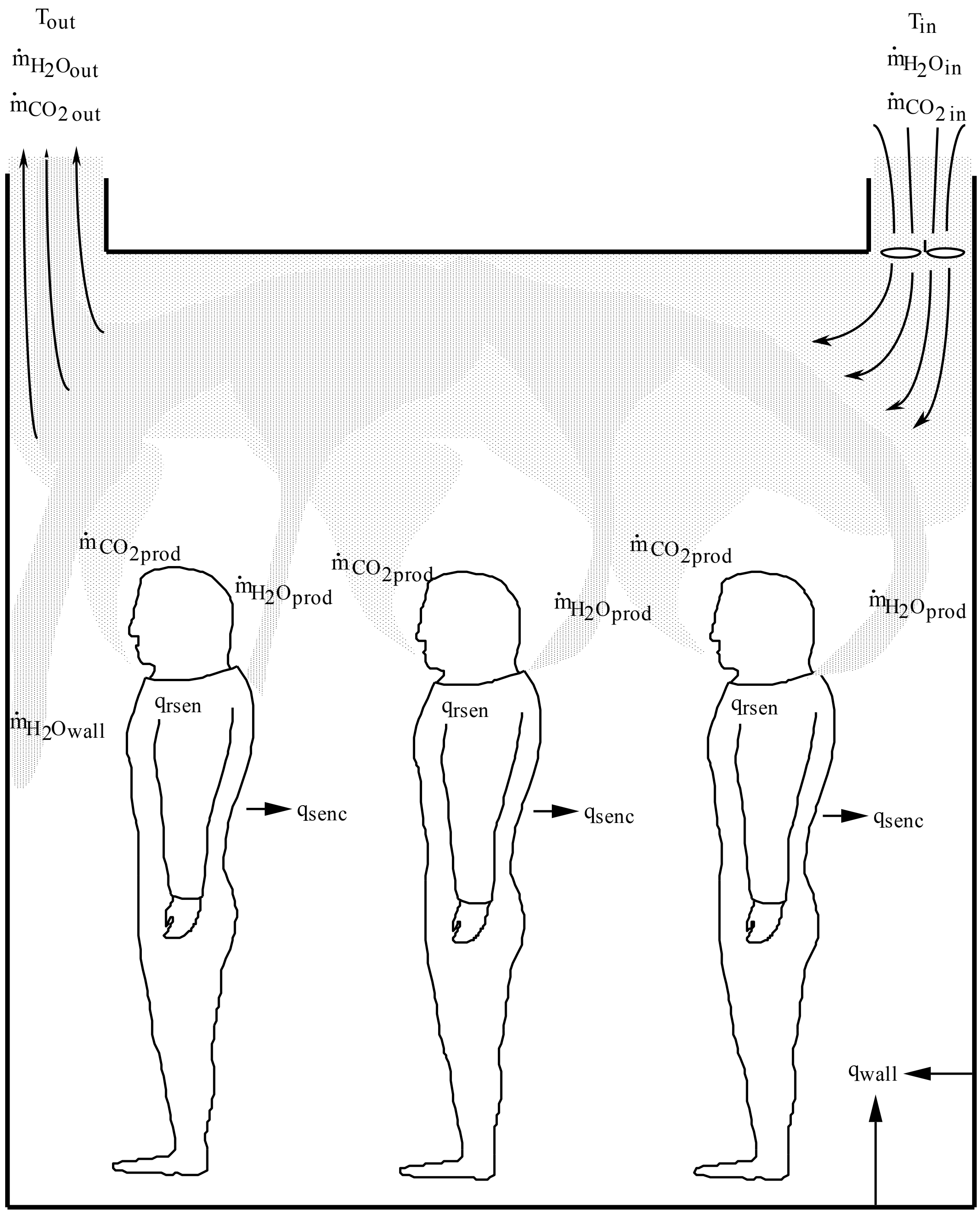


Figure 3.11 Heat and Mass Transfer in Postlanding Environment

3.5.1 Rate of Oxygen Consumption and Carbon Dioxide Production

The O_2 utilization of a subject is calculated by a simple formula:

$$\dot{m}_{O2cons} = q_{met}\,(2.0265\text{x}10^{-4} - 4.5055\text{x}10^{-5}\,R_{resp}) \quad (\text{lbm/hr})$$

where $\dot{m}_{O2cons}$ is the rate of O_2 disappearance and R_{resp} is the respiratory quotient, the ratio of the number of CO_2 molecules produced to O_2 molecules consumed. The O_2 consumption rate is then used with the respiratory quotient to determine the CO_2 production rate:

$$\dot{m}_{CO2prod} = \dot{m}_{O2cons} \left(\frac{44.0}{32.0}\right) R_{resp} \qquad \text{(lbm/hr)}$$

3.5.2 Cabin Temperature Analysis

To determine cabin dry gas temperature, the cabin is treated as a control volume. The stored heat of the cabin gas is equated to the sum of the change in enthalpy from inlet to outlet and the convective heat transfer with the walls and the crew members.

- Change in Enthalpy of Cabin Gas
  The inlet and outlet mass flow rates are assumed to be approximately the same. Therefore, change in enthalpy from inlet to outlet is merely the change in internal energy of the gas:

$$q_{enth} = \dot{m}_{gas}\, c_{p_g} (T_{cab} - T_{in}) \qquad \text{(Btu/hr)}$$

  where T_{cab} is considered to be uniform and equal to the outlet temperature.

- Convective Heat Transfer with the Cabin Walls
  Two pathways of heat transfer are considered with the cabin walls: convection and condensation.

  The equations used for convective heat transfer between the gas and the walls are:

$$q_{wall} = 0.0212\, A_{wall} (P_{cab} V_{cab})^{0.5} (T_{cab} - T_{wall}) \qquad \text{(Btu/hr)}$$

  for forced convection, and

$$q_{wall} = 0.06\, A_{wall} \left[G\, (P_{cab})^2 \left| T_{cab} - T_{wall} \right| \right]^{0.25} (T_{cab} - T_{wall}) \qquad \text{(Btu/hr)}$$

  for free convection, where A_{wall} is the convective area of cabin wall. Note that these equations are very similar to the convection equations in Section 3.4 (see Appendix G for derivation) [6].

- Total Sensible Convection with the Crew, q_{tsen}
  The equations for sensible convection have already been described. For shirt-sleeve mode, only the sensible convection (skin and respiratory) with each crew member needs be considered. For the suited modes, the convection with the inside suit surface is also pertinent. Thus:

$$q_{tsen} = N (q_{senc} + q_{rsen}) \quad \text{(Btu/hr)}$$

for shirt-sleeve modes, and

$$q_{tsen} = N (q_{senc} + q_{rsen} + q_{IS}) \quad \text{(Btu/hr)}$$

for IVA and helmet-off modes, where N is the number of crew members.

The differential equation which is used to determine cabin temperature is therefore:

$$m_{gas}\, c_{p_g} \frac{dT_{cab}}{dt} = \dot{m}_{gas}\, c_{p_g} (T_{cab} - T_{in}) + q_{tsen} + q_{wall} \quad \text{(Btu/hr)}$$

where dt is the time step used in the forward difference procedure and the mass of the gas in the cabin, m_{gas} is calculated using the cabin volume and the ideal gas law. It should be noted that this equation is based on dry gas analysis and does not account for latent heat from the crew members or condensation on the walls. Also constant pressure conditions are assumed. Thus, this equation should not be applied if latent heat is significant or if large pressure gradients might occur within the enclosure.

3.5.3 Cabin Dew Point Analysis

To determine the cabin dew point, a differential equation of the mass balance of the water vapor in the cabin gas is used. The change in the mass of water vapor in the cabin with time is equal to the sum of the water vapor production rate of the crew members and the net mass flow-rate of water vapor into the cabin, less the condensation rate on the walls.

- Water Vapor Production of the Crew

  The water vapor production rate, $\dot{m}_{H_2Oprod}$, is calculated from the total latent heat rate (described above) of the crew:

$$\dot{m}_{H_2Oprod} = N \frac{q_{lat}}{1040} \quad \text{(lbm/hr)}$$

  where, again, 1040 is the latent heat of water at 95 °F in Btu/lbm .

- Net Water Vapor Flow Rate
  The inlet gas stream may have a different humidity than the outlet stream. The following equation accounts for this:

$$\dot{m}_{H_2Onet} = \dot{m}_{H_2Oin} - \dot{m}_{H_2Oout} \quad \text{(lbm/hr)}$$

- Condensation Rate on the Walls

The equations for water vapor condensation rate from the walls are very similar to the maximum evaporative capacity equations in Section 3.4, Modes of Operation:

$$\dot{m}_{wall} = \frac{0.126}{1040} A_{wall} \left(\frac{V_{cab}}{P_{cab}}\right)^{1/2} (T_{cab} + 460)^{1.04} (P_{Tdew} - P_{Twall}) \text{ (lbm/hr)}$$

for forced convection and

$$\dot{m}_{wall} = \frac{1.32}{1040} A_{wall} \frac{T_{cab} + 460}{P_{cab}} \left\{ P_{cab}\, G \left| 0.005\, P_{cab} (T_{dew} - T_{wall}) + 1.02 (P_{T_{dew}} - P_{T_{wall}}) \right| \right\}^{1/4} (P_{T_{dew}} - P_{T_{wall}}) \quad \text{(lbm/hr)}$$

for free convection where A_{wall} is the convective area of the cabin and $(P_{Tdew} - P_{Twall})$ is the difference between the water vapor pressure of the cabin gas and the saturation pressure at the wall temperature. The greater of the two are used to calculate the condensation rate. Note that this equation will also account for evaporation from the walls.

The water vapor equation is therefore:

$$\frac{d(m_{H2O})}{dt} = \dot{m}_{H2Oprod} + \dot{m}_{H2Onet} - \dot{m}_{wall} \quad \text{(lbm/hr)}$$

This equation is solved for m_{H2O}. The cabin dew point is then determined by interpolation of a dew point versus vapor pressure curve (see Section 5.4.1, Function DEWPT). Since this equation is dependent on cabin gas temperature, the same restrictions apply, i.e. not accurate for conditions with large latent loads or transients in cabin pressures.

3.5.4 Carbon Dioxide Levels in a Cabin or Space Suit Helmet

The change in carbon dioxide levels is equal to the sum of the net CO_2 mass flow rate into the closed environment and the CO_2 production rate of the crew member(s).

- Net CO_2 Mass Flow Rate

$$\dot{m}_{CO2net} = \dot{m}_{CO2in} - \dot{m}_{CO2out} \quad \text{(lbm/hr)}$$

- CO_2 Mass Balance

Using the CO_2 expiration rate ($\dot{m}_{CO2prod}$) defined in Section 3.5.1, the differential mass balance equation for CO_2 is:

$$\frac{d(m_{CO2})}{dt} = \dot{m}_{CO2net} + \dot{m}_{CO2prod} \qquad \text{(lbm/hr)}$$

which is solved for m_{CO2} and the CO_2 partial pressure in the closed environment.

4 PROGRAM USAGE

Variable names in capital letters used in this Section are FORTRAN variable names that are used in the 41-node transient metabolic man program (METMAN) and described in Section 5.2, Primary Variable Description.

4.1 INPUT DESCRIPTION

4.1.1 Input Format

All input is by means of Namelist (free-field input) as described in the Sperry Series 1100 FORTRAN (ASCII) Level 11R1 Reference Manual. To the METMAN user, this is a convenient form of inputting data, especially if changes to individual variables are desired between cases. To input a data file (one or more variables), the following rules must be followed:

(1) The first line begins with a currency symbol ($) or ampersand (&) in column 2 followed by INPUT and a blank.

(2) Variables are input to METMAN by using the variable name (in Tables 4.1 and 4.2), followed by an "=" and the value. A comma follows the value to separate the variable from the next input variable. Input is "free field"; i.e. columns are not important, except lines can't begin in column 1 and must terminate before column 73; blanks are ignored, except that blanks cannot be used in variable values.

(3) The data file is terminated by $ or & beginning in column 2 and followed by END.

Example:

```
                         COLUMN NUMBER RULER
         10        20        30        40        50        60        70
123456789^123456789^123456789^123456789^123456789^123456789^123456789^12
 $INPUT
       Variable1 = XX.XX, Variable2 = T, . . . , Variablen = X.X,
       Variablen+1 = XX.XX,
       Variablen+2 = F,
       Array1 (U,V) = X.X, X.X, X.X, X.X, X.X, X.X, X.X, X.X, X.X, X.X,
       X.X, . . ., X.X,
       Array2 (U) = W*XXX.X, . . ., XXX.X,
 $END
```

where X, U, V, and W are numbers, T and F are logical constants, and Variable_i and Array_i are replaced by actual METMAN names. The array indices U and V are optional. The W*XXX.X entry is an allowable shorthand signifying W consecutive entries of a specific value XXX.X.

For each imposed case, specified variable values can be changed by including an assignment block immediately after $END of the preceding case:

```
                         COLUMN NUMBER RULER
         10        20        30        40        50        60        70
123456789^123456789^123456789^123456789^123456789^123456789^123456789^12
 $INPUT
       Variable1 = YY.YY, Variable2 = YY, . . . , Variablen = Y.Y,
       Variablen+1 = YY.YY,
 $END
```

Note that unspecified variables retain their values from the end of the previous case. This procedure is repeated for each additional case.

The data file consists of a set of initial conditions and any number of sets of imposed conditions as determined by MCASES.

To input a set of initial conditions, the user provides values for all the input variables, which are required according to the mode of operation selected, that describe the initial environmental conditions in which the man is to be placed. To input a set of imposed conditions (after running a set of initial conditions) or to input alternative initial conditions, the user selects those input variables (environmental conditions) which he/she wants to change, and inputs only those variables. All variables not changed will remain set at the values previously assigned to them, except maximum program time (SETI), which is always reset to zero after the initial case.

4.1.2 Control of Input Processing

The control of input processing is accomplished largely through two input variables, MCASES and STEPF.

A set of initial conditions is read, and METMAN calculates and prints out at intervals determined by PRINTI until steady state or maximum program time is reached. Steady state is achieved if the instantaneous heat storage rate (STORAT) is less than 2 Btu/hr and changes less than 0.1% between iterations.

METMAN will then check the present value of MCASES. If MCASES = 0, a new set of initial conditions will be read. This option allows multiple cases of possible initial conditions to be run in order to study the effect of altering specific variables or to choose a set of initial conditions which will reach a desired starting point for imposed cases (see Figure 4.1).

Initial Condition 1	$\longrightarrow$	Steady State or SETI 1
Initial Condition 2	$\longrightarrow$	Steady State or SETI 2
Initial Condition 3	$\longrightarrow$	Steady State or SETI 3
⋮		⋮
Initial Condition n	$\longrightarrow$	Steady State or SETI n

Figure 4.1 Input Processing for MCASES = 0

If MCASES = 1, the final values for the initial case will be used as starting conditions for a set of imposed conditions which will be read and run to steady-state or to maximum time, whichever comes first. Additional pairs of cases, if provided, will be run in the same fashion: the first case as an initial condition and the second case as an imposed case (see Figure 4.2). If a step function variable is set to true, STEPF=T, the initial cases are unaffected, but the imposed cases are constrained to run in series to the maximum time specified.

If MCASES > 1, the final values arrived at for the initial case will be saved and used as starting points for imposed cases, and METMAN will read a set of imposed conditions and proceed as before. If STEPF=F, allows a parametric study to be made, i.e. the final values of the initial case are saved and used as the starting points for a number of imposed cases. If STEPF=T, a series of imposed conditions can be simulated with each imposed case starting from the final values of the previous case (see Figure 4.3)--SETI must be input for

each imposed case, and each SETI value must be greater than those of preceding cases. Note also that if the number of imposed cases exceeds MCASES then the excess cases are run as independent initial cases, unless MCASES is reset in an imposed case to ≥ 1.

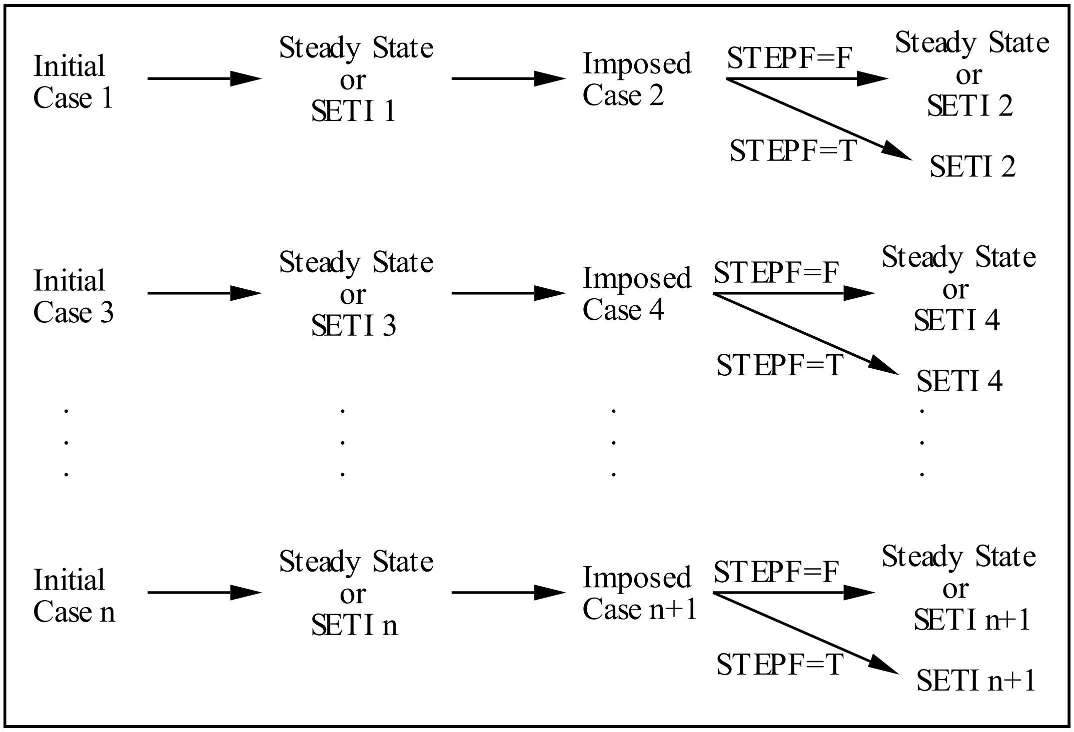


Figure 4.2 Input Processing for MCASES = 1

Refer to Table 4.1 for the variable names and a description of all input which is classified accordingly: (1) man, (2) cabin, (3) undergarment, (4) pressure suit, (5) liquid-cooled garment (LCG), (6) program, and (7) postlanding atmospheric conditions.

Refer to Table 4.2, for specific input requirements and options according to mode. In Table 4.2, an NR indicates that the variable is not required input for the given mode. Variables for which there is a numeric value assigned or marked with an asterisk (*) are required input. The numeric values given in the table are the latest available for those variables at the time of publication of this document, and are included only as suggested values. The variables marked with an asterisk are to be given values strictly at the option of the user i.e., the user should input any value he feels is reasonable.

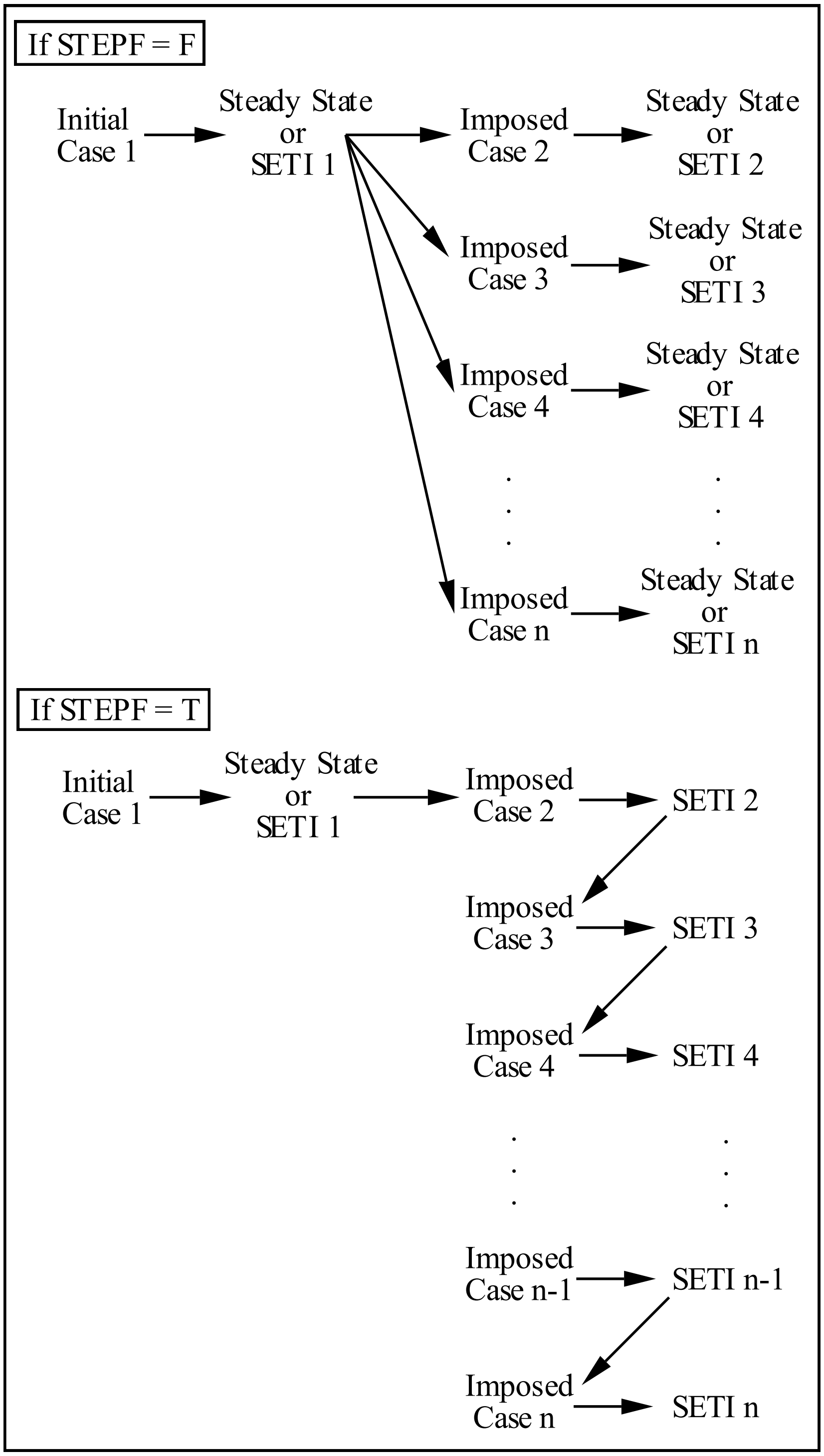


Figure 4.3 Input Processing for MCASES > 1

Values listed for AKS (suit conductivity) and ALS (suit thickness) are used to represent the Apollo-era suit which had seven layers of Multi-Layer Insulation (MLI). Alternative AKS values for a 5-layer Shuttle Suit have been determined for three general Shuttle flight EVA environments referred to as Hot, Neutral, and Cold. Suit conductances were derived for an inside suit temperature of 75 °F and outside suit temperatures of 200 °F, 70 °F and -60 °F, respectively. The corresponding values of AKS are 0.000301 for Hot, 0.00214 for Neutral and 0.000151 for Cold. An ALS value of 0.0033 was assumed. The Hot and Cold environments roughly correspond to the Sun and Dark cases of Table 4.2. The helmet AKS and ALS values from this table can be used for the Shuttle helmet.

The variables described in Table 4.1 and Table 4.2 are input as constant values. However, 18 of these variables can be varied with time by inputting curves and initiating a curve interpolation subroutine of METMAN. The input variables necessary for this option are presented in Table 4.3. If any of these variables are input as functions of time, the curve interpolation must be initiated in METMAN by setting CURVES = .TRUE. in the input file. For each of the 18 variables, three additional variables are input to accomplish the interpolation. The first is a logical variable which is set to true if its associated variable is input as a function of time (default is false). The second is an integer variable indicating the number of points in the curve, which has a maximum of 25 points. The third is a doublet array with spaces for up to 25 pairs of time vs. input variable value data; time is followed by its corresponding variable value, followed by the next time and its variable value, and so on. The 18 input variables for which the curve option currently exists are:

AKS (Helmet)	CFMS	MODE	PCAB
PGC	PO2	RM	TCAB
TDEW	TDEWC	TGIN	TW
TWI	UEFF	VCAB	WF

and

AKS (suit)	QASRB

The last two variables apply to the suit segments, and for this reason have two dimensional arrays.

Table 4.1
Input Variable Definitions and Specifications

Input Variables	Eng. Symbols	Definitions and Specifications	Index
MODE		0 = shirt-sleeves; 1 = normal suited; 2 = EVA; 3 = helmet off.	2.1-2.4
AC	A_C	Total convective area, ft^2 (Standing = 19.5; sitting = 15.5; prone = 12.5)	3.12
AR	A_R	Total radiative area, ft^2. (Standing = 15.5; sitting 11.5; prone = 9.5.) These values for shirt-sleeves case only. If the mode is 1, 2, or 3, AC is as above, and AR = AC.	3.13
AVRM		Average metabolic rate logical (AVRM = .TRUE. if RM is based on average metabolic rate for standard man--RM will be adjusted to account for body size; AVRM = .FALSE. if RM is based on empirical profile for specific subject--RM will not be adjusted to account for body size) [9]. Default: .FALSE.	5.26
HEIGHT	H	height, in (Standard man = 67; 95th percentile male = 72.5; 5th percentile female = 60.5). Default : 67.	3.7, B.1-B.4
RM	Q_{me}	Metabolic rate, Btu/hr	3.7-3.8
RQ	R_{resp}	Respiratory quotient, the ratio of moles of CO_2 produced to moles of O_2 consumed. Default: 0.82.	3.46
UEFF	U_{eff}	Useful work efficiency, percent.	3.8
WEIGHT	M	Subject weight, lbm (Standard man = 154; 95th percentile male = 215; 5th percentile female = 103). Default: 154.	3.7, B.1-B.4
CABIN			
G	G	Gravity ratio (earth = 1.0; moon = 0.167; space = 0.0)	3.28-3.31
PCAB	P_{cab}	Cabin gas pressure, psia.	3.28
TCAB	T_{cab}	Cabin gas temperature, °F.	3.28
TDEWC	T_{dew}	Cabin gas dew point, °F.	3.48
TW	T_{wall}	Temperature of cabin walls, °F.	3.47

Input Variables	Eng. Symbols	Definitions and Specifications	Index
VCAB	V_{cab}	Cabin gas free-stream velocity, ft/min.	3.28-3.31, 4.26
VF	F	View factor	3.31
UNDERGARMENT			
AKUG		Conductivity of undergarment, Btu/hr ft °F	
ALUG		Thickness of undergarment, ft.	
EUG	ε_{ug}	Emissivity of undergarment.	3.31
SUIT			
CFMS		Suit gas flow, CFM.	
CPG	C_{p_g}	Specific heat of gas, Btu/lbm-°F. IPURGE = .FALSE. if normal gas flow).	3.17
IPURGE		Purge flow logical (IPURGE = .TRUE. if dry gas purge). Default: .TRUE.	
PG		Total suit pressure, psia.	
PO2		Oxygen pressure in suit, psia.	
TDEW		Dew point of gas into suit, F (must be ≤ TGIN, unless IPURGE = .TRUE.).	5.68-5.69
TGIN		Temperature of gas into suit, °F.	
VOLHMT		Helmet volume, ft^3.	
SUIT ARRAYS			
ACSUIT	A_{OS}	Convective area of suit segment, ft^2	3.42
ARSUIT	A_{OS}	Radiative area of suit segment, ft^2	3.42
AKS		Conductivity of suit segment, Btu/ft-°F-hr.	4.7
ALS		Thickness of suit segment, ft.	4.7
EIS	ε_{IS}	Emissivity of inside suit segment.	3.42
EOS	ε_{OS}	Emissivity of outside suit segment.	3.42
CPS	c_{p_S}	Specific heat of suit segment, Btu/lbm-°F.	3.44
QASRB	Q_{abs}	Absorbed incident heat flux on suit segment, Btu/hr-ft^2.	3.43
WS		Weight of suit segment, lbm.	

Input Variables	Eng. Symbols	Definitions and Specifications	Index
LIQUID-COOLED GARMENT			
CPW	C_{p_w}	Specific heat of LCG coolant, Btu/lbm-°F.	3.16
ITHERM		LCG option for isothermal inlet water (for each time step: if ITHERM = .TRUE. and UASB .GT. 0.0 then TWI is calculated from Subroutine SRTLCG, based on Apollo PLSS performance and comfort zones (see Section 4.4.1, p. 4.41); if ITHERM = .TRUE. and UASB .LE. 0.0 then, within a 45 to 90 °F temperature range, TWI is increased by 1 °F when shivering is greater than 50.0 Btu/hr and decreased 1 °F when stored heat is greater than 50 Btu; if ITERM = .FALSE. then TWI is constant).	3.16
LCG		Liquid cooled garment logical (LCG = .TRUE. if LCG parameters are desired to be printed in input and output listing)	
TWI	T_{inlet}	Temperature of cooling liquid into LCG, °F.	3.16
UASB		Heat transfer coefficient of sublimator, Btu/hr-°F. Option to calculate new inlet temperature to LCG (TWI) based on PLSS performance. If UASB .GT. 0.0 then Apollo PLSS model (Subroutine SRTLCG) is used to determine TWI.	
WF	$\dot{m}_{lcg}$	Liquid flow, lbm/hr (if WF = 0.0, then TWI, CPW, and UAG are ignored.)	3.15
PROGRAM			
DT		Time increment (calculation interval), min (0.05 min is recommended for the highest degree of accuracy).	
MCASES		Number of imposed cases.	4.3-4.5
PRINTI		Print interval, min	4.3
SETI		Maximum time for each case, min.	4.3-4.5
POSTLANDING			
AREAW	A_{wall}	Cabin wall area, ft^2	3.49
CFMC		Postlanding fan capacity, CFM.	
CPA		Specific Heat of Atmosphere, Btu/lbm-°R	
IPLOP		Postlanding option logical (IPLOP = .TRUE. for postlanding conditions).	

Input Variables	Eng. Symbols	Definitions and Specifications	Index
NUMEN	N	Number of crew members.	3.47-3.48
PA		Atmospheric pressure, psia (default = 14.7).	
PN2A		Nitrogen partial pressure in atmosphere, psia.	
PO2A		Oxygen partial pressure in atmosphere, psia.	
RA		Atmospheric gas constant, ft-lbf/lbm-R (default = 53.3).	
TATM		TATM	
TDEWA		Atmospheric dew point, °F.	
TWALPL	T_{wall}	Wall temperature during postlanding, °F.	3.47
VOLCAB		Volume of cabin, ft^3	

Table 4.2
Input File Examples

Array elements used for each body segment are defined as follows:

1	- Trunk	6	- Right hand
2	- Right arm	7	- Left hand
3	- Left arm	8	- Right foot
4	- Right leg	9	- Left foot
5	- Left leg	10	- Head

	Input Data			
Input Variable	Shirt Sleeves	Normal Suited	EVA	Suited Without Helmet
MAN				
MODE	0	1	2	3
AC	19.5	19.5	19.5	19.5
AR	15.5	19.5	19.5	19.5
RM	*[1]	*	*	*
UEFF	*	*	*	*
AVRM	*	*	*	*
HEIGHT	*	*	*	*
WEIGHT	*	*	*	*
RQ	*	*	*	*
CABIN				
G	*	*	NR	*
PCAB	*	*	NR	*
TCAB	*	*	NR	*
TDEWC	*	*	NR	*

[1] *Signifies required input. Floating point entries are suggested values for required input. NR (see next page) means input is not required

Input Variable	Shirt Sleeves	Normal Suited	EVA	Suited Without Helmet
	Input Data			
TW	*	*	NR	*
VCAB[1]	*	*	NR	*
VF	1.0	1.0	NR	*
UNDERGARMENT				
AKUG	0.046	0.046	0.046	0.046
ALUG	0.0141	0.0141	0.0141	0.0141
EUG	0.90	0.90	0.90	0.90
SUIT				
CFMS	NR	*	*	*
CPG	0.24	0.22	0.22	0.22
IPURGE	FALSE	*	*	*
PG	NR	*	*	*
PO2	NR	*	*	*
TDEW	NR	*	*	*
TGIN	NR	*	*	*
VOLHMT	NR	0.1968	0.1968	NR
SUIT ARRAYS				
ACSUIT(1)	NR	9.82	9.82	9.82
ACSUIT(2)	NR	2.95	2.95	2.95
ACSUIT(3)	NR	2.95	2.95	2.95
ACSUIT(4)	NR	5.96	5.96	5.96
ACSUIT(5)	NR	5.96	5.96	5.96
ACSUIT(6)	NR	0.81	0.81	0.81
ACSUIT(7)	NR	0.81	0.81	0.81

	Input Data			
Input Variable	Shirt Sleeves	Normal Suited	EVA	Suited Without Helmet
ACSUIT(8)	NR	1.81	1.81	1.81
ACSUIT(9)	NR	1.81	1.81	1.81
ACSUIT(10)	NR	2.52	2.52	NR
ARSUIT(1)	NR	9.82	9.82	9.82
ARSUIT(2)	NR	2.95	2.95	2.95
ARSUIT(3)	NR	2.95	2.95	2.95
ARSUIT(4)	NR	5.96	5.96	5.96
ARSUIT(5)	NR	5.96	5.96	5.96
ARSUIT(6)	NR	0.81	0.81	0.81
ARSUIT(7)	NR	0.81	0.81	0.81
ARSUIT(8)	NR	1.81	1.81	1.81
ARSUIT(9)	NR	1.81	1.81	1.81
ARSUIT(10)	NR	2.52	2.52	NR
ALS(1)	NR	The values reported here for AKS and ALS are		
ALS(2)	NR	based on Apollo-era suit with 7 MLI.		
ALS(3)	NR	ALS (suit thickness) for suit layers excluding		
ALS(4)	NR	helmet is dependent on PCAB:		
ALS(5)	NR	If PCAB = 0.0, ALS(1 - 9) = 0.0078		
ALS(6)	NR	If PCAB > 0.0, ALS(1 - 9) = 0.0156		
ALS(7)	NR	ALS for the helmet is constant:		
ALS(8)	NR	MODE = 1, ALS(10) = 0.0050		
ALS(9)	NR	MODE = 2, ALS(10) = 0.0210		
ALS(10)	NR			
		AKS(1-9)		AKS(10)

Input Variable	Input Data: Shirt Sleeves	Normal Suited	EVA	Suited Without Helmet
AKS(1)	NR	Sun with and without vehicle:		
AKS(2)	NR		0.000383	0.02155
AKS(3)	NR	Dark with vehicle:		
AKS(4)	NR		0.000269	0.00167
AKS(5)	NR	Dark without vehicle		
AKS(6)	NR		0.000255	0.00181
AKS(7)	NR	Cabin (pressurized)		
AKS(8)	NR		0.023000	0.10000
AKS(9)	NR	Cabin (depressurized)		
AKS(10)	NR		0.000255	0.00181
EIS(1)	NR	0.90	0.90	0.90
EIS(2)	NR	0.90	0.90	0.90
EIS(3)	NR	0.90	0.90	0.90
EIS(4)	NR	0.90	0.90	0.90
EIS(5)	NR	0.90	0.90	0.90
EIS(6)	NR	0.90	0.90	0.90
EIS(7)	NR	0.90	0.90	0.90
EIS(8)	NR	0.90	0.90	0.90
EIS(9)	NR	0.90	0.90	0.90
EIS(10)	NR	0.90	0.90	NR
EOS(1)	NR	0.837	0.837	0.837
EOS(2)	NR	0.837	0.837	0.837
EOS(3)	NR	0.837	0.837	0.837
EOS(4)	NR	0.837	0.837	0.837

	Input Data			
Input Variable	Shirt Sleeves	Normal Suited	EVA	Suited Without Helmet
EOS(5)	NR	0.837	0.837	0.837
EOS(6)	NR	0.837	0.837	0.837
EOS(7)	NR	0.837	0.837	0.837
EOS(8)	NR	0.837	0.837	0.837
EOS(9)	NR	0.837	0.837	0.837
EOS(10)	NR	0.860	0.860	NR
CPS(1)	NR	0.22	0.22	0.22
CPS(2)	NR	0.22	0.22	0.22
CPS(3)	NR	0.22	0.22	0.22
CPS(4)	NR	0.22	0.22	0.22
CPS(5)	NR	0.22	0.22	0.22
CPS(6)	NR	0.22	0.22	0.22
CPS(7)	NR	0.22	0.22	0.22
CPS(8)	NR	0.22	0.22	0.22
CPS(9)	NR	0.22	0.22	0.22
CPS(10)	NR	0.30	0.30	NR
QASRB(1)	NR	NR	*	NR
QASRB(2)	NR	NR	*	NR
QASRB(3)	NR	NR	*	NR
QASRB(4)	NR	NR	*	NR
QASRB(5)	NR	NR	*	NR
QASRB(6)	NR	NR	*	NR
QASRB(7)	NR	NR	*	NR
QASRB(8)	NR	NR	*	NR

Input Variable	Input Data: Shirt Sleeves	Normal Suited	EVA	Suited Without Helmet
QASRB(9)	NR	NR	*	NR
QASRB(10)	NR	NR	*	NR
WS(1)	NR	22.6	22.6	22.6
WS(2)	NR	4.53	4.53	4.53
WS(3)	NR	4.53	4.53	4.53
WS(4)	NR	7.65	7.65	7.65
WS(5)	NR	7.65	7.65	7.65
WS(6)	NR	0.995	0.995	0.995
WS(7)	NR	0.995	0.995	0.995
WS(8)	NR	3.68	3.68	3.68
WS(9)	NR	3.68	3.68	3.68
WS(10)	NR	4.56	4.56	NR
LCG				
CPW	1.0	1.0	1.0	1.0
ITHERM	*	*	*	*
LCG	*	*	*	*
TWI	*	*	*	*
USAB	*	*	*	*
WF	*	*	*	*
PROGRAM				
DT	0.05	0.05	0.05	0.05
MCASES	*	*	*	*
PRINTI	*	*	*	*
SETI	*	*	*	*

Input Variable	Input Data Shirt Sleeves	Normal Suited	EVA	Suited Without Helmet
POSTLANDING				
AREAW	*	*	NR	*
CFMC	*	*	NR	*
CPA	*	*	NR	*
IPLOP	*	*	FALSE	*
NUMEN	*	*	NR	*
PA	*	*	NR	*
PN2A	*	*	NR	*
PO2A	*	*	NR	*
RA	*	*	NR	*
TATM	*	*	NR	*
TDEWA	*	*	NR	*
TWALPL	*	*	NR	*
VOLCAB	*	*	NR	*

Table 4.3

Input Explanation for Curve Data

METMAN provides a curve interpolation option for 18 of the input variables which can be initiated by inputting the appropriate logical constant for CURVES:

CURVES = .TRUE.:Curve interpolation portion of METMAN is initiated. Required if one or more variables are input as functions of time.

CURVES = .FALSE.: No curve data are being input (default).

Given a hypothetical input variable, XXX, three variables (one logical variable, one integer variable and one array) must be supplied in lieu of XXX to interpolate a time vs. XXX curve:

<u>Logical Variable</u>

CXXX = .FALSE.: XXX is input as a constant value. Default = .FALSE.

CXXX = .TRUE.: XXX is interpolated from a curve using time as the independent variable.

<u>Integer Variable</u>

NPXXX Number of pairs of time versus XXX data.

<u>Array</u>

CCXXX Spaces for up to 25 pairs of time versus XXX data. Time is followed by the corresponding XXX value followed by the next time and its XXX value, etc. In all cases time is in hours. The units for the dependent variable values can be found by referring to Table 4.1.

The following is a list of the 18 input variables and the corresponding curve variables.

Table 4.3 Input Explanation for Curve Data

The following is a list of the 18 input variables and the corresponding curve variables.

	Input	Curve Variables		
Description	Variable	Logical	Integer	Array
Suit Conductivity	AKS	CAKS[2]*	NPAKS	CCAKS
Helmet Conductivity	AKS	DAKS	OAKS	DDAKS
Gas Flow Rate	CFMS	CCFMS	NPCFMS	CCCFMS
Mode	MODE	CMODE	NPMODE	CCMODE
Cabin Pressure	PCAB	CPCAB	NPPCAB	CCPCAB
Suit Gas Pressure	PGC	CPGC	NPPGC	CCPGC
Suit Oxygen Pressure	PO2	CPO2	NPPO2	CCPO2
Suit Absorbed Incident Heat	QASRB	CQASRB	NPQASB[3]**	CCQASB
Metabolic Rate	RM	CRM	NPRM	CCRM
Cabin Temperature	TCAB	CTCAB	NPTCAB	CCTCAB
Suit Inlet Dew Point	TDEW	CTDEW	NPTDEW	CCTDEW
Cabin Dew Point	TDWC	CTDWC	NPTDWC	CCTDWC
Suit Inlet Gas Temperature	TGIN	CTGIN	NPTGIN	CCTGIN
Wall Temperature	TW	CTW	NPTW	CCTW
LCG Inlet Coolant Temperature	TWI	CTWI	NPTWI	CCTWI
Work Efficiency	UEFF	CUEFF	NPUEFF	CCUEFF
Cabin Free-Stream Velocity	VCAB	CVCAB	NPVCAB	CCVCAB
LCG Coolant Flow Rate	WF	CWF	NPWF	CCWF

[2] *CAKS = .TRUE. for interpolation of time vs. conductivity data pairs for all suit segments excluding the helmet. The dependent variable AKS is assumed to be the same for all segments. The helmet conductivity is interpolated separately through DAKS.

[3] **CQASRB = .TRUE for interpolation of time vs. absorbed incident heat for each suit segment. The dependent variable QASRB is not assumed to be the same for all suit segments. CCQASB(I,J) has spaces for 25 pairs of time vs. absorbed incident heat for each segment: I = time vs. incident heat pairs; J = 1 is trunk; J = 2 right arm; J = 3 left arm; J = 4 right leg; J = 5 left leg; J = 6 right hand; J = 7 left hand; J = 8 right foot; J = 9 left foot; J = 10 helmet

4.1.3 Effective Cabin Gas Velocity

The absolute velocity of the cabin gas is typically estimated by dividing the flow rate of the cabin gas by the average cross section area of the interior cabin space. However the actual heat loss by convection is higher than predicted by the absolute velocity. This discrepancy is due to the motion of the crew members which tends to increase the relative speed of the body segments with the gas stream. For this reason a relationship of effective cabin gas velocity vs. metabolic rate has been developed to more reliably predict convection with the skin/undergarment or suit exterior (see Figure 4.4). Given the metabolic rate of a crew member, the effective cabin gas velocity is obtained from this relationship and added to the actual cabin gas velocity to determine VCAB.

4.2 EXECUTION DESCRIPTION

Executable versions of METMAN are currently maintained on three computers:

1) DEC VAX 8650, Crew and Thermal Systems Division, Johnson Space Center.
2) DEC VAX 8650, Lockheed Engineering and Sciences Company.
3) Sperry UNISYS 1194-P, Johnson Space Center.

Execution is accomplished with runstreams, presented below.

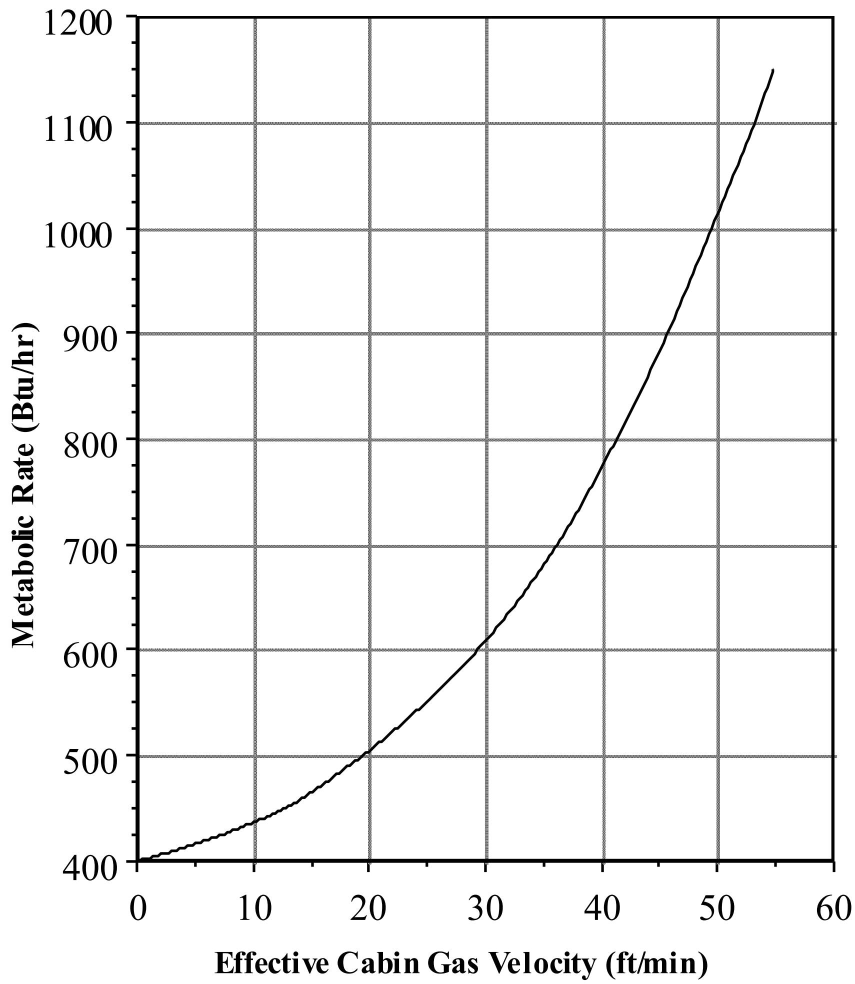


Figure 4.4 Metabolic Rate vs. Effective Cabin Gas Velocity

4.2.1 METMAN Execution on the VAX 8650

To run METMAN in BATCH mode use the following command:

$SUBMIT/NOPRINT/NOTIFY/QUE=<batch queue> <batch>

where <batch> is a command file which invokes the demand execution runstream. A suggested command file for <batch> is listed in Table 4.4. Note that in Table 4.4 <filename1.DAT> and <filename2.DAT> are again the user defined input and output files and must be specified in

<batch> prior to submitting the batch run. Also, <dirname>.<subdir> denotes the names of the user's main directory and subdirectory where the METMAN library is stored.

Demand runs are executed with the command:

$@<runstream.COM> <filename1.DAT> <filename2.DAT>

where <runstream.COM> is the user's runstream and <filename1.DAT> and <filename2.DAT> are the user's input and output files, respectively. If the input and output files are not included with the execution command, they will be solicited on-screen. A suggested runstream is listed in Table 4.5.

Table 4.4

Suggested METMAN Execution Runstream

for Batch Processing on VAX 8650

```
$ SET NOVERIFY
$ SET NOON
$ SET PROC/NAME = "METMAN Batch"
$ SET ON
$ @[<dirname>.<subdir>]<runstream.COM> [<dirname>.<subdir>]<filename1.DAT> -
  [<dirname>.<subdir>]<filename2.DAT>
$ BYE
```

Table 4.5
Suggested METMAN Execution Runstream for VAX 8650

```
$ ! COMMAND PROCEDURE WHICH ACCEPTS INPUT & OUTPUT FILE NAMES
$ ! AND ASSIGNS THEM TO UNITS 1 & 2.
$ !                          J. IOVINE 3/23/89
$ !
$ DELETE [<dirname>.<subdir>]MAIN.EXE;1
$ IF P1 .EQS. "" THEN GOTO NAME
$ GOTO UNITS
$ !
$ NAME:
$ WRITE SYS$OUTPUT "  "
$ INQUIRE IN " ENTER INPUT FILE NAME"
$ INQUIRE OUT " ENTER OUTPUT FILE NAME"
$ P1 := 'IN'
$ P2 := 'OUT'
$ UNITS:
$ !
$ ! ASSIGN UNIT 1 TO INPUT FILE
$ ASSIGN 'P1' FOR001
$ !
$ ! ASSIGN UNIT 2 TO OUTPUT FILE
$ ASSIGN 'P2' FOR002
$ !
$ ! EXTRACT MAIN OBJECT FILE FROM 41LIB
$ LIB/EXTRACT= MAIN/OUTPUT= [<dirname>.<subdir>]MAIN-
  [<dirname>.<subdir>]41LIB
$ !
$ ! LINK MAIN WITH 41LIB
$ LINK/NOMAP/EXEC= [<dirname>.<subdir>]MAIN.EXE [<dirname>.<subdir>]MAIN,-
  [<dirname>.<subdir>]41LIB/LIB
$ DELETE [<dirname>.<subdir>]*.OBJ;*
$ !
$ ! RUN PROGRAM
$ RUN [<dirname>.<subdir>]MAIN.EXE
$ WRITE SYS$OUTPUT "  "
$ EXIT
```

4.2.2 METMAN Execution on the UNISYS 1194-P

Execution of METMAN on the UNISYS is typically of short duration. For this reason METMAN is usually run in demand mode on this system. METMAN is executed by the command:

```
>@ADD,L <.element>
```

where <.element> is the user's name for the METMAN runstream element which has been copied into the temporary program file, TPF$. A suggested runstream element is listed in Table 4.6. Note that lines 4 through 12 of this runstream contain edits to subroutine SUIT which is then recompiled by line 13. These lines should be deleted by the user for a typical run, but are included as an example of how, for special purposes, METMAN can be edited within a runstream without making changes to the original code.

4.2.3 METMAN Termination and Accuracy

METMAN is terminated when steady state conditions or the maximum case time (SETI) has been reached for all cases (see Section 4.1.2). Two conditions must be satisfied simultaneously in order to reach steady state: 1) the absolute value of the storage rate for the subject is less than 2 Btu/hr, ABS(STORAT) < 2, and 2) the change in the total instantaneous storage rate with one time step is less than 0.1 % of the total storage rate, ABS((OLDSTR - STORAT)/STORAT) < 0.001.

The highest degree of output accuracy is obtained by using a calculation interval (DT) of 0.02 minutes, and should be used for transient studies. For a study of steady-state end points, a calculation interval of 0.05 may be used.

Note: 41IN is the input element, 41OUT is the output file, 41MAP is the program map element and 41RUN is the runstream element.

Table 4.6

Suggested METMAN Execution Runstream for UNISYS 1194-P

with a Temporary Program Editing Example (Lines 4 – 13)

```
Line #
1               @FREE TPF$.
2               @ASG,T TPF$.,F///2000
3               @COPY EC2-L01925*A41NODE.,TPF$.
4               @ED,U SUIT
5               251
6               C / /C/2
7               256
8               R      DTLCG = 0.001
9               258
10              R      N = II(I)
11              I      QW(I) = UAG * PCFLO(I) * ( T(N) - TWI )
12              EXIT
13              @FTN,OZE TPF$.SUIT
14              @ED,IQ 41MAP
15              IN TPF$.
16              LIB JSC*FTNLOCAL.
17              LIB JSC*FTN.
18              @PACK
19              @PREP
20              @DELETE,C 41OUT.
21              @ASG,CP 41OUT.
22              @BRKPT PRINT$/OUT
23              @PRT,S 41RUN
24              @PRT,S 41IN
25              @MAP 41MAP
26              @XQT 41MAP
27              @ADD 41IN
28              @BRKPT PRINT$
29              @FREE 41OUT.
```

4.3 OUTPUT DESCRIPTION

The number of lines of output can be controlled by changing the input variable PRINTI (print interval). Output forms and formats are listed and explained in Table 4.7. If other variables values are desired as output, they can be printed in a list by inserting the following FORTRAN statement into the source code:

```
WRITE (o,<namelist>)
```

where "o" is the number for the appropriate output device and <namelist> is the name of an existing or added namelist . If the values of the namelist variables are desired at each print interval, the above statement should be included after WRITE (o,TEST) statements in the main program. If the namelist variables are desired at the termination of each initial and each imposed case, the above statement should be included after WRITE (o,1001) T statements in the main program.

Table 4.7

Output Forms and Formats

Heading	Explanation
	Shirt-Sleeve Case
TIME, MIN	Time in minutes.
TEMP WATER OUT, F	Temperature of water out of the LCG, °F.
TEMP HEAD CORE, F	Temperature of the head core node, °F.
AV. TEMP SKIN, F	Weighted average temperature of skin, °F.
TEMP UNDERGARMENT, F	Weighted average temperature of undergarment, °F.
Q SENSIBLE, BTU/HR	Total heat loss from the undergarment by radiation to walls, by convection to air, by conduction from skin to liquid-cooled garment, and by convection from lungs to air.
Q EVAP, BTU/HR	Heat loss by sweat evaporation.
Q LATENT, BTU/HR	Heat loss by sweat and diffusion, and latent loss by respiration.
HEAT STORAGE RATE, BTU/HR	Rate at which heat is being stored in body.
SHIVER RATE, BTU/HR	Rate at which heat is being generated due to shivering.
TOTAL HEAT STORAGE, BTU	Total heat stored by body (a comfort criterion). Above approximately 400 Btu, life functions are impaired. Above approximately 900 Btu, life functions are terminated.

Additional Output if the POSTLANDING option is used:

CABIN TEMP F	Cabin temperature during postlanding, °F.

Heading	Explanation
DEW POINT F	Cabin dew point during postlanding, °F.
CO2 PRESS	Cabin CO2 partial pressure during postlanding, mm Hg.

<u>Suited Case</u>

TIME, MIN	Time in minutes.
TEMP GAS OUT, F	Temperature of gas out of suit, °F.
TEMP HEAD CORE, F	Temperature of head core node, °F.
AV. TEMP SKIN, F	Weighted average temperature of skin, °F.
TEMP OF INSIDE OF SUIT, F	Weighted average of temperature of inside of pressure suit, °F.
TEMP OF OUTSIDE OF SUIT, F	Weighted average of temperature of outside of pressure suit, °F.
Q OUT OF SUIT, BTU/HR	Heat loss through suit wall, also known and the suit heat leak; (+) out of suit, (-) into suit.
Q SENSIBLE, TOTAL, BTU/HR	Heat loss from undergarment to inside surface of suit by radiation, to gas in suit by convection, and from skin to liquid-cooled garment by conduction, and by convection from lungs to air.
Q EVAP, BTU/HR	Heat loss by evaporation of sweat.
Q LATENT, BTU/HR	Total heat loss by evaporation of sweat, diffusion, and latent heat loss from lungs.
HEAT STORAGE RATE, BTU/HR	Rate at which heat is being stored in body.
SHIVER RATE, BTU/HR	Rate at which heat is being generated by shivering.
TOTAL HEAT STORAGE, BTU	Total heat stored by body. Above approximately 300 Btu, life functions are impaired. Above approximately 1000 Btu, life functions are terminated.

Heading	Explanation
Additional output for POSTLANDING option with helmet off:	
CABIN TEMP, °F	Cabin dry-bulb temperature, °F.
DEW POINT T, °F	Cabin dew point, °F.
CO2 PRESS, mm Hg	CO2 partial pressure in cabin, mm Hg.
Liquid Cooled Garment (any mode)	
LCG inlet water temperature, F	Self-explanatory.
LCG outlet water temperature, F	Self-explanatory.
LCG water temperature difference, F	Temperature difference between the inlet and the outlet of the LCG.
Suit inlet dew point, F	Self-explanatory.
Suit inlet dry bulb temperature, F	Self-explanatory.
Oxygen used, lb	Self-explanatory.
C02 produced, lb	Self-explanatory.
Total water evaporation from body, lb	Self-explanatory.
Feed water used, lb	Self-explanatory.
Metabolic rate, Btu/hr	Self-explanatory.
Water flow rate, lb/hr	Coolant flow rate in the LCG.
Namelist TEST (Printed every PRINTI)	
EMTOT	Total maximum heat transfer rate by evaporation, Btu/hr.
QD	Total latent diffusion heat transfer rate, Btu/hr.
QR	Total latent respiratory heat transfer rate, Btu/hr.
SCONV	Total sensible convection between the man and the suit gas stream, Btu/hr.
SLCG	Total heat transfer rate to LCG, Btu/hr.
SQOSA	Total convective heat transfer rate between the outside suit surface and the atmosphere, Btu/hr.

Heading	Explanation
SQOSW	Total radiation heat transfer rate between the outside suit surface and the cabin walls, Btu/hr.
SQUGA	Total convection heat transfer rate between the man and the environment (Shirt-sleeve only), Btu/hr.
SQUGW	Total radiation heat transfer rate between the man and the enclosure (inside suit or cabin walls), Btu/hr.
SROR	Sweat run off rate; latent heat of sweat production in excess of maximum evaporation rate, Btu/hr.
T4	Temperature of head skin, °F.
T5	Temperature of trunk core, °F.
T8	Temperature of trunk skin, °F.
T12	Temperature of right arm skin, °F.
T20	Temperature of right leg skin, °F.
TAVSKIN	Average skin temperature, °F.
TDEWOT	Dew point at suit outlet, °F.
UAG	Heat transfer coefficient between man and LCG.

4.4 OUTPUT INTERPRETATION

For non-extreme input conditions, the overall thermal status of a subject can be evaluated from the output by considering comfort zones. If a severe environment is considered, the program will warn the user of potential danger or death to the subject.

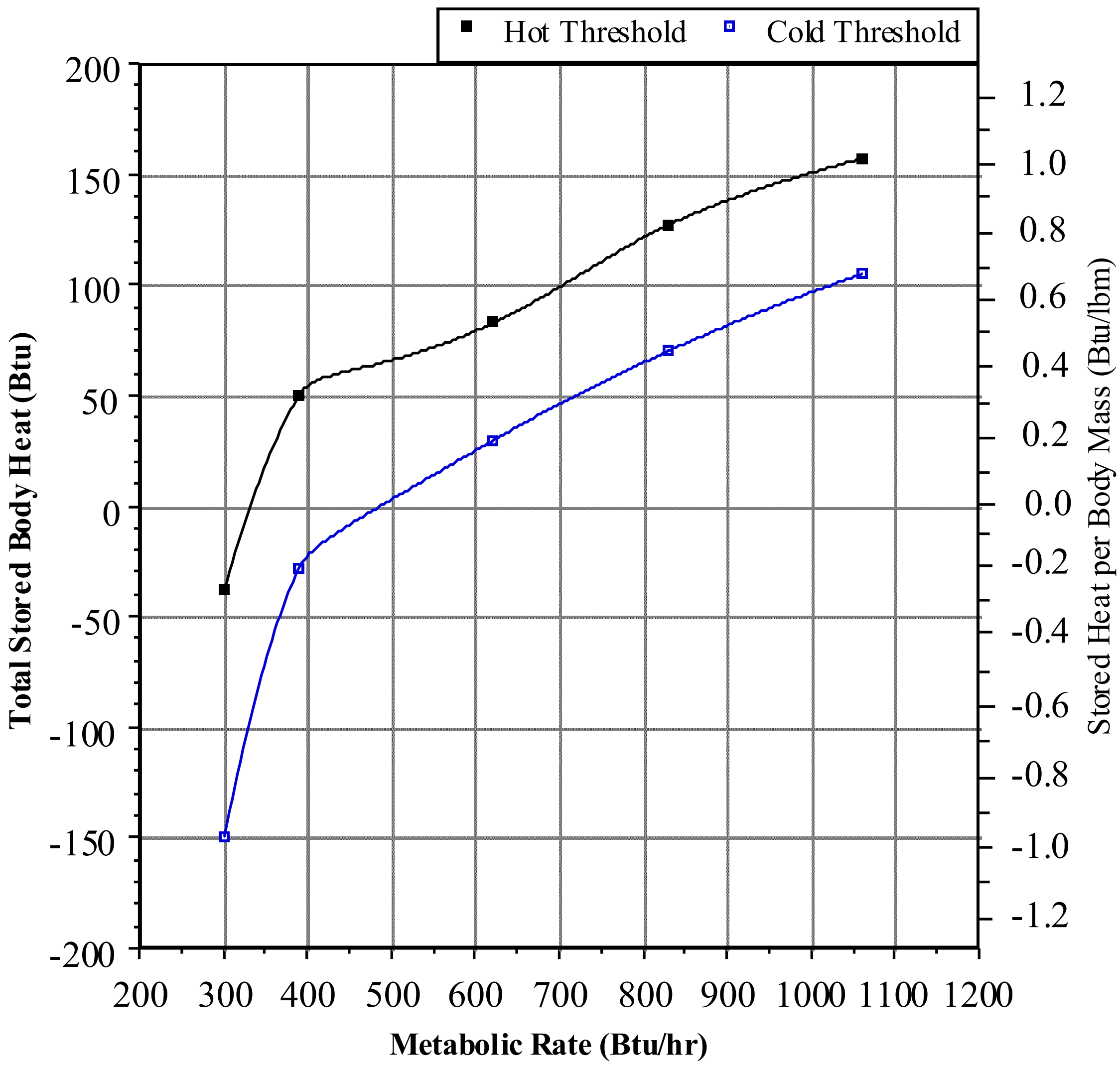
4.4.1 Comfort Zones

A comfort zone is a region of a graph of metabolic rate vs. total stored heat. The upper and lower borders of the comfort zone are curves delineating the thresholds of hot and cold discomfort, respectively. If the point defined by the metabolic rate and total stored heat of a subject is between the two curves, the subject is expected to be thermally comfortable. Comfort zones have been established for shirt-sleeve and suited cases and are presented in Figure 4.5 and Figure 4.6, respectively. The shirt sleeve comfort zone is based on empirical data from a standard-sized man of 154 lbm and 67 inches [10]. The comfort zone for the suited case is determined by the comfort criteria equation:

$$Q_{comfort} = \frac{q_{met} - 278.0}{13.2} \pm 65.0 \qquad \text{(Btu)}$$

For an average-size person the total stored heat and metabolic rate data from the output can be plotted on this graph, using the left-hand vertical axis to assess the thermal comfort. For a large or small person, the total stored heat should be divided by the subject weight and this value and the metabolic rate can be plotted using the right hand vertical axis which is normalized for body weight. The metabolic rate need not be normalized since it is either input as an absolute value by the user (AVRM = .FALSE.) or is adjusted for body size by

Figure 4.5: Shirt-Sleeve Comfort Zone



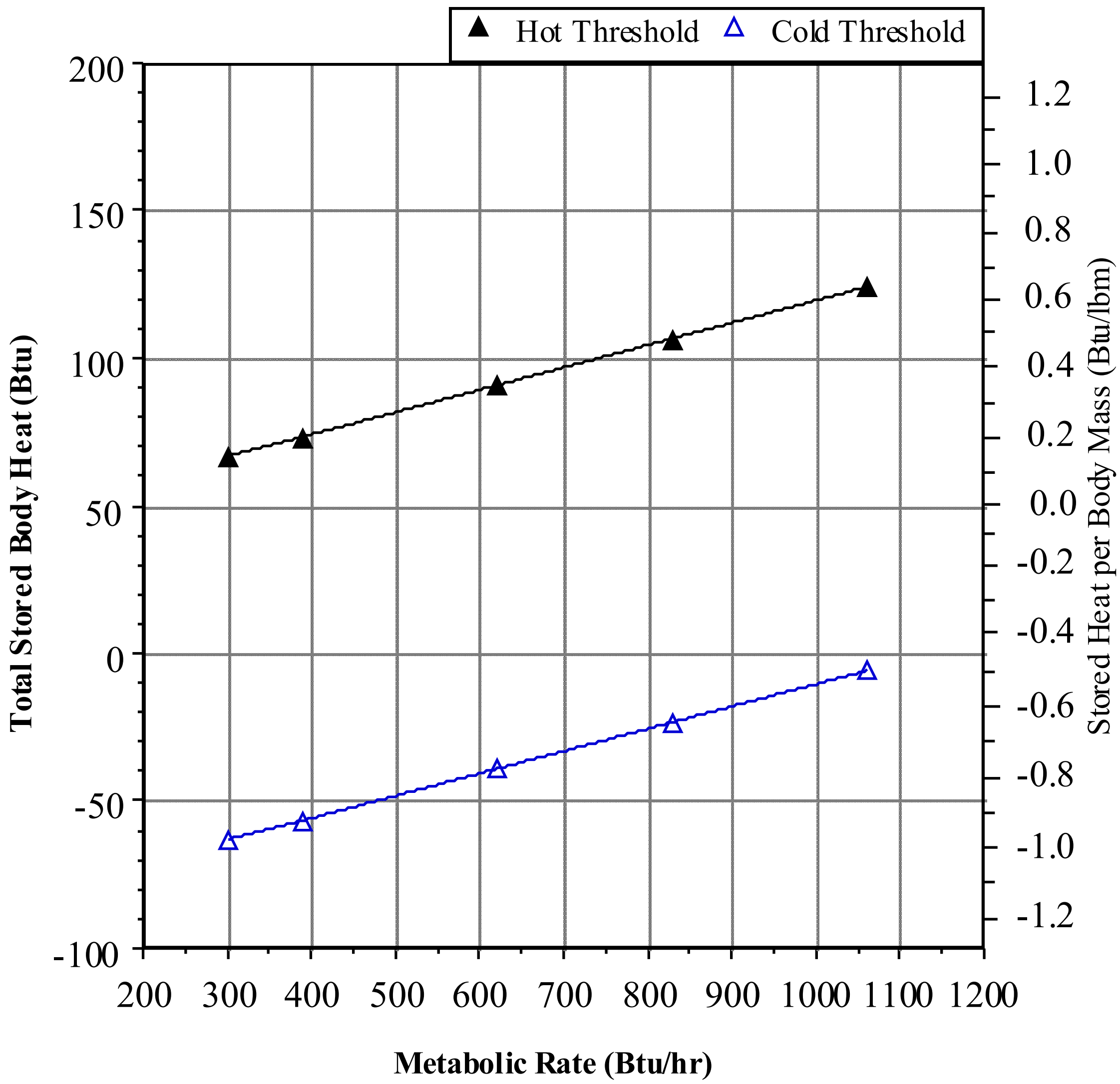


Figure 4.5 Shirt-Sleeve Comfort Zone

the program (AVRM = .TRUE., [9])--the metabolic rate listed in the output will be correct for this purpose in either case.

4.4.2 Warning Messages

In cases of severe heat stress the thermal discomfort of the subject is certain, and performance and safety become critically important. In these conditions the heat rejection mechanisms of the body, LCG and suit are insufficient and the body temperature becomes elevated. Therefore warning messages are displayed in the output to alert the user that at a certain point in the simulation the heat build-up in the subject has reached potentially dangerous or fatal levels. After each time step METMAN checks the total stored heat of the man. If it is greater than 300 Btu, then the following message is written to the output file in bold letters:

LIFE FUNCTIONS ARE
IMPAIRED

However, if the total stored heat is greater than 1000 Btu, the message is:

LIFE FUNCTIONS ARE
TERMINATED

In the latter case, the program is halted after writing the final values of the output variables. It should be noted that the critical criteria for displaying these messages is based on a standard-size man (154 lbm). For large or small subjects the user should divide the total stored heat by the body weight . This value should be determined by the user after every print interval. The normalized critical criteria are:

$$\frac{\text{Total Stored Heat}}{\text{Body Weight}} > 2 \text{ Btu/lbm: Life functions are impaired.}$$

$$\frac{\text{Total Stored Heat}}{\text{Body Weight}} > 6.5 \text{ Btu/lbm: Life functions are terminated.}$$

5 SUBROUTINE AND FUNCTION DOCUMENTATION

The purpose, method, and usage of METMAN are described in Sections 1.0 through 4.0. In this section the METMAN subroutines are similarly documented. The general flow chart of the main program begins the section; it provides an overall sense of how the program works and how the subroutines are related. This is followed by primary variable definitions, the definitions of important variables which are used by METMAN and are common to some subroutines. The subroutines and the functions are then documented.

5.1 GENERAL FLOW CHART FOR THE MAIN PROGRAM

The main program and subprogram general flow charts are shown in Figures 5.1A through 5.1F.

5.2 PRIMARY VARIABLE DEFINITIONS

Table 5.1 is a listing of the descriptions of the primary variables used internally in the program:

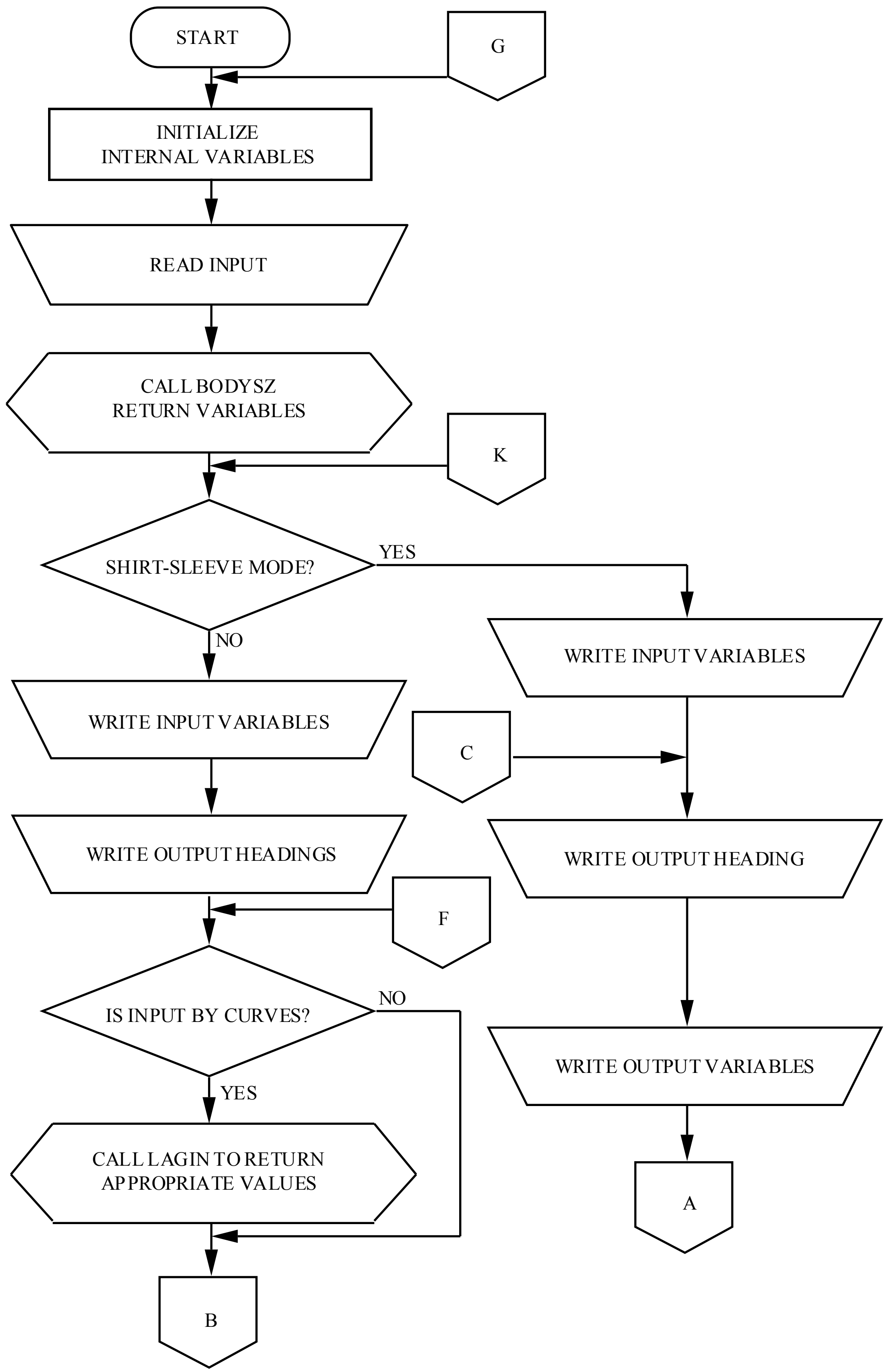


Figure 5.1A Main Program General Flow Chart

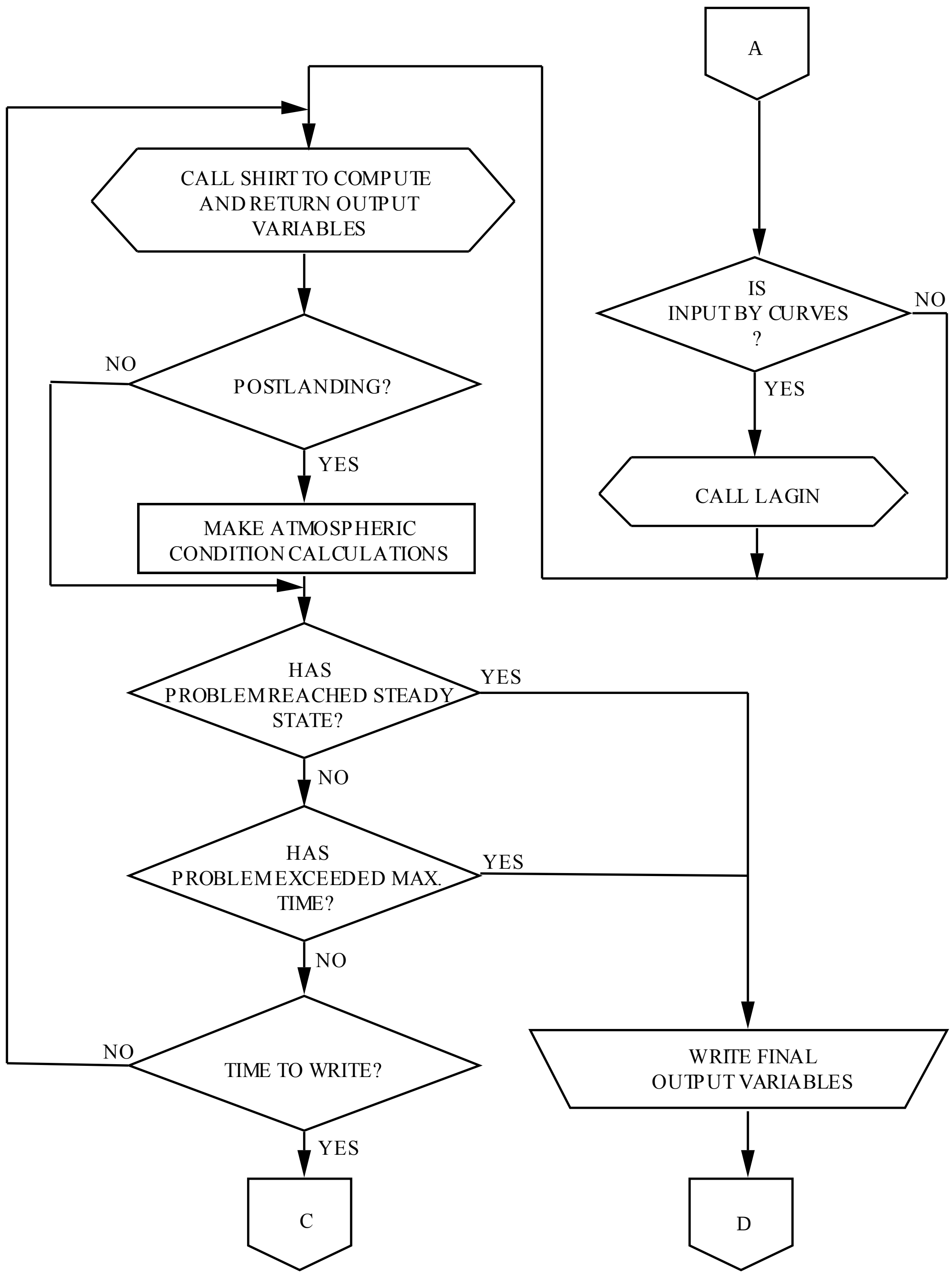


Figure 5.1B Main Program General Flow Chart (Continued)

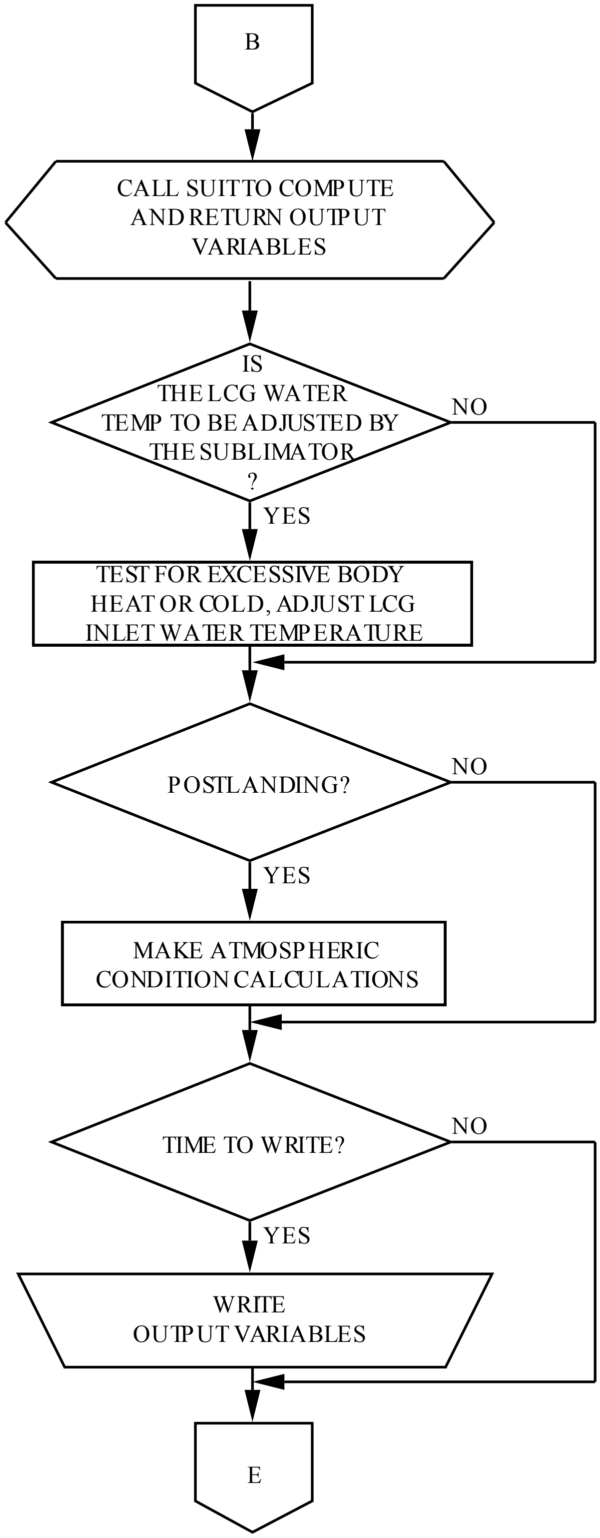


Figure 5.1C Program General Flow Chart (Continued)

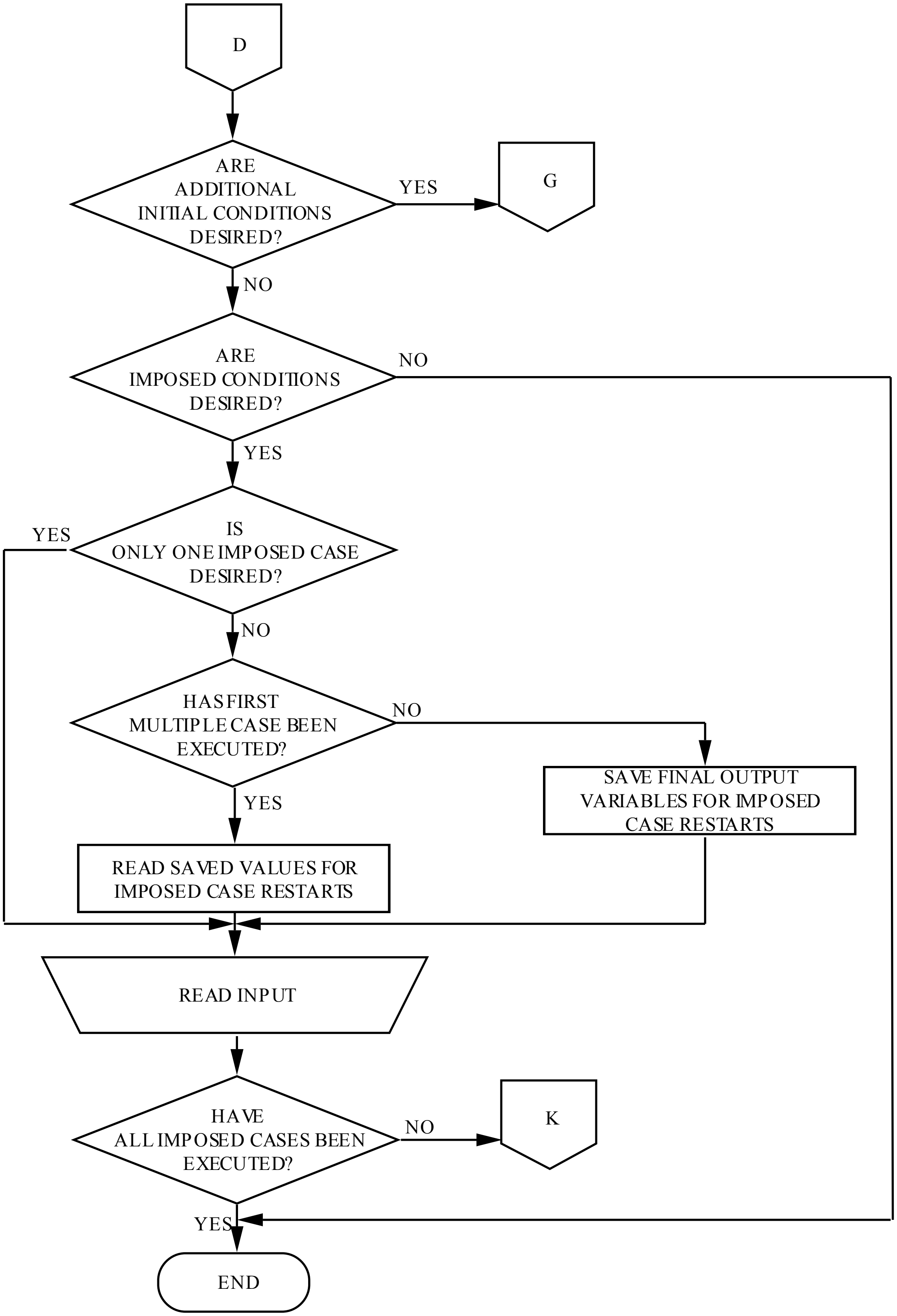


Figure 5.1D Program General Flow Chart (Continued)

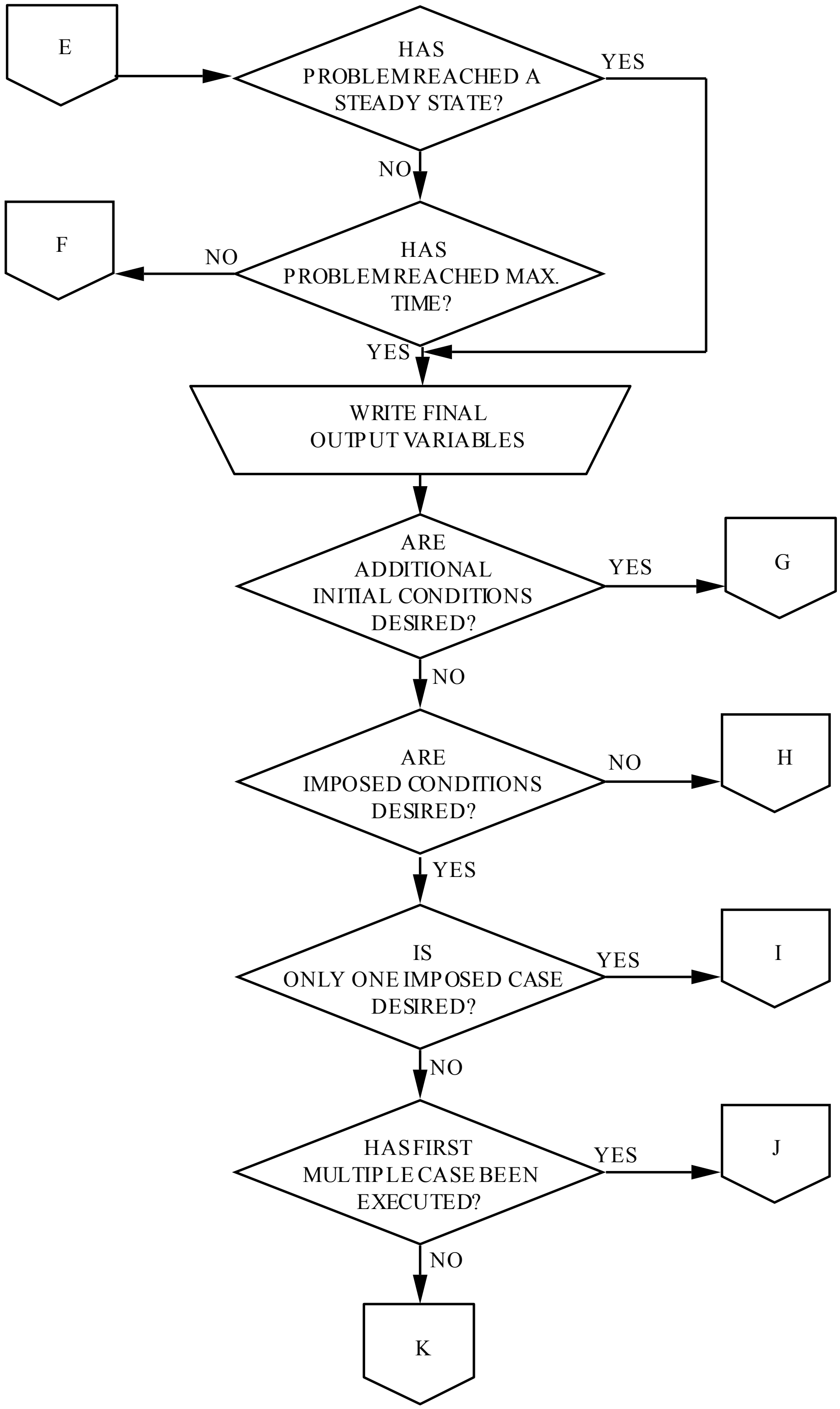


Figure 5.1E Program General Flow Chart (Continued)

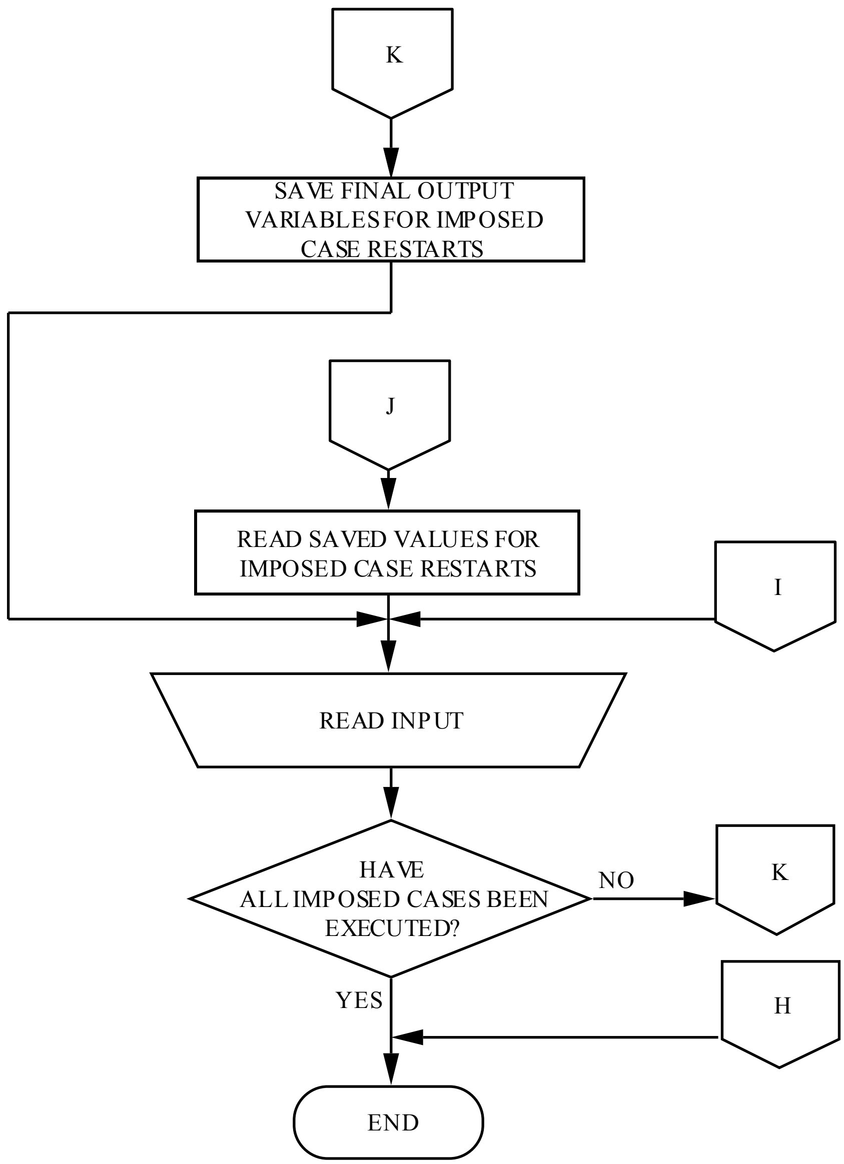


Figure 5.1F Program General Flow Chart (Continued)

Table 5.1
Primary Variable Descriptions

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
ACE(I)	A_C	Convective area of each skin segment, ft^2.	Man	3.12
ACSUTE(I)	A_{OS}	Convective area of each suit segment, ft^2.	Suit	3.43
AKST		Intermediate storage for the conductivity of each suit segment (except the Suit helmet) as read from a time-dependent curve, Btu/hr ft-°F.		
ARE(I)	A_R	Area of radiation of each skin segment, ft^2.	Man	3.13
ARSUTE(I)	A_{OS}	Area of radiation of each suit segment, ft^2.	Suit	3.43
BF(I)	$\dot{m}_i$	Blood flow to each compartment, lbm/hr.	Man	3.10
BFBFAC(I)		Basal blood flow rates to each compartment for standard man, liters/hr.	Man	
C(I)	C_i	Heat capacitance of each compartment, Btu/lbm-°F.	Man	3.19
CLO		Effective thickness/conductivity of undergarment, Btu/hr-ft^2-°F.	Man	
CMT	$\bar{h}_{D,j}$	Mass transfer coefficient for each segment, ft/hr.	Suit	3.42, H.7-H.12
CN1	g_c	Conductivity of core compartments of each body segment, kcal/hr-cm-°C.	Man	D.2-D.5
CN2	g_m	Conductivity of muscle compartments of each body segment, kcal/hr-cm-°C.	Man	D.2-D.5
CN3	g_f	Conductivity of fat compartments of each body segment, kcal/hr-cm-°C.	Man	D.2-D.5
CN4	g_s	Conductivity of skin compartments of each body segment, kcal/hr-cm-°C.	Man	D.2-D.5
CO2GEN	$\dot{m}_{CO2prod}$	CO_2 generation rate from crew during postlanding, lbm/hr.	Postlanding	3.46
CO2IN	$\dot{m}_{CO2in}$	Flow rate of CO_2 from the atmosphere to the cabin during postlanding, lbm/hr.	Postlanding	3.50
CO2MMH		Cabin CO_2 partial pressure during postlanding, mm Hg.	Postlanding	
CO2OUT	$\dot{m}_{CO2out}$	Flow-rate CO_2 out of the cabin during postlanding, lbm/hr.	Postlanding	3.50

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
COLD(I)		For bodycompartments with temperatures less than the set point temp., it is the absolute value of the temperature difference from set point; otherwise = 0.0, °F.	Postlanding	
DELAY		Length of time since last diverter valve change, hr.	LCG	
DELTAT		LCG coolant temperature difference from inlet to outlet,°F	LCG	
DENSA		Density of atmosphere outside spacecraft during postlanding, lbm/ft^3.	Postlanding	
DENSC		Density of cabin atmosphere during postlanding, lbm/ft^3.	Postlanding	
DEPTC	l_j	Length of each body segment, cm.	Man	D.2
DEWPT		Function which returns dewpoint in °F for a given vapor pressure in mm Hg.	FUNCTION	
DILAT	$\dot{m}_{dilate}$	Blood flow source term for vasodilation to skin, lbm/hr-°F.	Man	3.25
DTIME		DT converted to hours for internal program use.	Program	
DTLCG		Effective temperature change of coolant as it passes through each LCG segment.	LCG	
EMAX(I)	E_{max}	Maximum evaporative heat transfer rate of each segment by forced convection (shirt-sleeve mode), Btu/hr.	Man	3.30, H.1-H.3
EMAX1(I)	E_{max}	Maximum evaporative heat transfer rate of each segment by free convection (shirt-sleeve mode), Btu/hr.	Man	3.30, H.3-H.7
EVA		Internal logical variable controlling portion of output format related to MODE 2.	Program	
FACTOR(I)	$G_j^{i \to i+1}$	Conductionheat transfer coefficients between adjacent compartments of each segment, Btu/hr-°F.	Man	D.3-D.4
FC(I)	$\bar{h}_j$	Convective heat transfer coefficient of each segment for suited modes, Btu/hr-ft^2-°F.	Man	3.37, G.5-G.7
FDWTR		Feed water used, lbm.	LCG	
FDWTRR		Feed water usage rate, lbm/hr.	LCG	

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
FR(I)		Coefficient of radiation heat exchange between man and inside suit wall of each segment, Btu/ft^2-°F.	Suit	
HC(I)	$\bar{h}_j$	Forced convection heat transfer coefficient of each segment, Btu/hr-ft^2-°F.	Shirt	3.28, G.1-G.3
HCO2MH		CO_2 pressure in helmet, mm Hg.	Suit	
HC1(I)	$\bar{h}_j$	Free convection heat transfer coefficient of each segment, Btu/hr-ft^2-°F.	Shirt	3.28, G.1-G.5
HGMM		Water vapor pressure in cabin atmosphere during postlanding, mm Hg.	Pos	
HR		Radiation heat transfer coefficient calculated for each segment, Btu/ft^2-°F.	Shirt	
ICOND		0 for initial conditions, 1 for imposed conditions.	Program	
II(I)		Integer array used for subscript manipulation of man's skin compartments and suit segments.	Program	
INIT		.TRUE. for first call of SHIRT or SUIT subroutines, .FALSE. thereafter.	Program	
KOUNT		Internal print control counter.	Program	
KOUNTR		Internal print control counter.	Program	
NUMEN	N	Number of crewmen in cabin, postlanding option.	Postlanding	3.47
OLDSTR		Heat storage rate (STORAT) saved from previous iteration for steady-state test, Btu/hr.	Main	
O2RATE		Oxygen usage rate of the crewman, lbm/hr.	Suit	
PCA(I)	K_s	Percent of surface area allocated to each segment.	Man	3.21-3.23
PCFLO(I)		Percent of total coolant flow rate to each LCG segment.	LCG	
PCO2		Partial CO_2 pressure in suit, psia.	Suit	
PCO2HT		CO_2 partial pressure in helmet, psia.	Suit	
PH2OI(I)	P_{in}	Inlet water vapor pressure to each suit segment, psia.	Suit	3.40
PH2OO(I)	P_{out}	Partial pressure of water vapor out of a segment if surface is wet, psia.	Suit	3.40, H.9-H.11
PH2OOO(I)		Actual water vapor partial pressure out of each suit segment, psia.	Suit	
PH2O5O		Partial pressure of water vapor at suit outlet, psia.	Suit	
PH2O1		Partial pressure of water vapor in suit trunk segment, psia.	Suit	

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
PH2O2		Partial pressure of water vapor in suit arm segments, psia.	Suit	
PH2O3		Partial pressure of water vapor in suit leg segments, psia.	Suit	
PH2O4		Partial pressure of water vapor in suit helmet segment, psia.	Suit	
PH2O5		Partial pressure of water vapor in suit hand segments, psia.	Suit	
PH2O6		Partial pressure of water vapor in suit feet segments, psia	Suit	
PLMSPR		Log mean square differential between the water vapor partial pressure of the inlet and outlet of the suit, and the saturated vapor pressure at the undergarment/skin temperature, psia.	Suit	
PN2		Partial nitrogen pressure in suit, psia.	Suit	
POSTN		Diverter valve position: 1 = minimum cooling; 2 = intermediate cooling; 3 = maximum cooling.	LCG	
PRINT		Internal variable PRINTI converted to hours.	Program	
PRNOW		Time for next printout, hr.	Program	
PTIM		Real spacecraft time of run, min.	Program	
PULSE		Pulse rate, strokes/min.	Man	
QB	$\dot{m}_{basal,i}$	Basal blood flow rate of each compartment, liters/hr.	Man	3.23-3.26, C.3
QCOND(I)	q_{cond}	Conduction between adjacent compartments, Btu/hr.	Man	3.10
QCONV(I)	q_{conv}	Convective heat transfer rate from blood to each compartment, Btu/hr.	Man	3.10-3.11
QD		Total diffusion heat transfer rate, Btu/hr.	Man	
QDIF(I)	q_{dif}	Diffusion heat transfer rate for each skin node, Btu/hr.	Man	3.30
QEMIT		Radiation emission rate of outer suit surface, Btu/hr.	Suit	
QEVAP		Total heat transfer rate by evaporation of sweat, Btu/hr.	Man	
QG(I)		Convection heat transfer rate from man and inside suit surface to the suit gas, Btu/hr.	Suit	
QIN	q_{enth}	Heat added to spacecraft atmosphere by addition of surrounding atmosphere during postlanding, Btu/hr	Postlanding	3.46
QISG(I)	q_{IS}	Heat transfer rate from inside of suit to gas stream, Btu/hr.	Suit	3.39-3.40
QLAT(I)		Heat transfer rate of evaporation, diffusion,and latent respiration, Btu/hr.	Man	
QLATTR	q_{rlat}	Latent respiratory heat transfer rate, Btu/hr.	Man	3.18
QLCG(I)	q_{lcg}	Heat transfer rate from man to liquid-cooled garment, Btu/hr.	LCG	3.15-3.16

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
QMET(I)	q_{met}	Metabolic heat production rate for each compartment, Btu/hr.	Man	3.7-3.8
QOSA(I)	q_{OSC}	Heat transfer rate for each segment from outside of suit to the atmosphere, Btu/hr.	Suit	3.40-3.41
QOSW(I)	q_{OSR}	Heat transfer rate for each segment from outside of suit to walls, Btu/hr.	Suit	3.43
QOUT		Heat removed from cabin atmosphere during postlanding, Btu/hr.	Postlanding	
QR		Latent and sensible heat transfer rate of respiration, Btu/hr	Man	
QRAD(I)	q_{rad}	Radiation heat transfer rate from each undergarment/skin compartment, Btu/hr.	Man	3.13
QRSEN1		Respiratory sensible heat transfer rate of head core, Btu/hr.	Man	
QRSEN2		Respiratory sensible heat transfer rate of head muscle, Btu/hr.	Man	
QRSEN3		Respiratory sensible heat transfer rate of head fat, Btu/hr.	Man	
QRSEN5		Respiratory sensible heat transfer rate of trunk core, Btu/hr.	Man	
QRSEN6		Respiratory sensible heat transfer rate of trunk muscle, Btu/hr.	Man	
QRSEN15	q_{rlat}	Total respiratory sensible heat transfer rate, Btu/hr.	Man	3.18
QSCONV		Total convective heat transfer rate from blood compartment, Btu/hr.	Man	
QSEN(I)	q_{sen}	Sensible heat transfer rate of each segment, Btu/hr.	Man	3.28-3.30
QSENT	q_{tsen}	Sensible heat generated by the crew during postlanding, Btu/hr.	Postlanding	3.47
QSHIV	q_{shiv}	Heat generation rate by shivering, Btu/hr.	Man	3.22
QSTOR	Q_{stor}	Total heat storage, Btu.	Man	3.20
QSTRMN		Lower limit of heat storage comfort range, Btu.	LCG	
QSTRMX		Upper limit of heat storage comfort range, Btu.	LCG	
QTSUIT		Total heat transfer rate through suit from inside to outside, Btu/hr.	Suit	
QUG(I)		Sensible plus LCG heat transfer rate from each undergarment/skin compartment, Btu/hr.	Man	
QUGA	q_{senc}	Convective heat transfer rate, calculated for each segment, of undergarment/skin to cabin gas, Btu/hr.	Shirt	3.28-30
QUGG(I)	q_{senc}	Convective heat transfer rate, from each undergarmen/skin compartment to gas stream,	Suit	3.37-3.39
QUGIS(I)	q_{rad}	Radiation heat transfer rate from each undergarment/skin segment to inside of suit, Btu/hr.	Suit	3.42
QUGW	q_{rad}	Heat transfer rate, calculated for each segment, from undergarment/skin	Shirt	3.31

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
		to cabin walls, Btu/hr.		
QW		Total heat transfer rate from man to LCG, Btu/hr.	LCG	
QWALL	q_{wall}	Forced convection from man to wall during postlanding, Btu/hr.	Postlanding	3.47
QWALL1	q_{wall}	Free convection from man to wall during postlanding, Btu/hr.	Postlanding	3.47
RADC	r_i	Outer boundary radius of each body compartment, cm.	Man	D.2
RADCM		Node radius of each body compartment, cm.	Man	
RCOEF1	κ_3	Body size proportioning factor.	Man	G.7, H.9
RCOEF2	κ_4	Body size proportioning factor.	Man	3.40, G.7
RCOEF3	κ_2	Body size proportioning factor.	Man	3.28,3.30, G.5
RGAS	R	Same as RA. Equal to RA if RA is input, or to weighted average of ft-lbf/lbm-°R.	Main	3.14
RHOCOA		CO_2 density in atmosphere surrounding spacecraft during postlanding, lbm/ft^3.	Postlanding	
RHOCO2		CO_2 density in spacecraft during postlanding, lbm/ft^3.	Postlanding	
RMIX	R	Gas constant for gas in suit, ft-lbf/lbm-°R.	Suit	3.14
RQ		Respiratory quotient of the crewman, that is, the ratio of CO_2 molecules produced per O_2 molecules consumed.	Main	
RSHCO1	κ_1	Body size proportioning factor.	Man	G.3, H.3
RSHCO2	κ_2	Body size proportioning factor.	Man	G.5, H.7
SAFACT		Surface areas for each body segment of a standard man, cm^2.	Man	
SAVT		Temperature of man element at end of initial conditions, °F.	Main	
SAVTG		Temperature of gas in suit at end of initial conditions, °F.	Main	
SAVTIS		Temperature of inside of suit at end of initial conditions, °F.	Main	
SAVTM		Average of temperatures of undergarment/skin at end of initial conditions, °F.	Main	
SAVTOS		Temperature of outside of suit at end of initial conditions, °F.	Main	
SAVTUG(I)		Temperature of undergarment/skin at end of initial conditions, °F.	Main	
SCABC		Total sensible heat transfer from man to surrounding gas, Btu/hr.	Man	
SCAB1		Sensible heat transfer from suit to cabin atmosphere and walls, Btu/hr.	Suit	

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
SCO2		Final value of CO_2 in spacecraft for postlanding initial case, lbm.	Postlanding	
SDENSC		Final value spacecraft atmospheric densityf for postlanding initial case, lbm/ft^3.	Postlanding	
SETT		SETI converted to hours for internal program use.	Program	
SHSO		Specific humidity at suit outlet.	Suit	
SPHCAB		Specific humidity in cabin outlet gas during postlanding, lbm H_2O vapor/lbm atmosphere.	Postlanding	
SPHUMA		Specific humidity of atmosphere around spacecraft during postlanding, lbm H_2O vapor/lbm atmosphere.	Postlanding	
SQOSA		Total convective heat transfer rate from outside of suit to cabin gas, Btu/hr.	Suit	
SQOSW		Total heat transfer rate from outside of suit to walls, Btu/hr.	Suit	
SQOSW		Total radiation heat transfer from outside of suit to cabin walls, Btu/hr.	Suit	
SQUG		Total sensible heat transfer rate from man to his immediate environment, Btu/hr.	Man	
SQUGA		Total convective heat transfer rate from undergarment/skin to cabin air, Btu/hr.	Shirt	
SQUGW		Total sensible heat transfer rate from man to walls, shirt-sleeve mode, Btu/hr.	Shirt	
SQW		Sum of heat transfer rate from man to LCG, Btu/hr.	LCG	
SROR		Sweat run-off rate, lbm/hr.	Man	
STCAB		Temperature of cabin, saved at the end of initial condition, °F.	Main	
STDEWC		Dewpoint temperature of cabin; saved at the end of initial condition, °F.	Main	
STGOUT		Gas temperature out of each suit element; saved at the end of initial condition, °F.	Main	
STORAT	q_{storat}	Heat storage rate, Btu/hr.	Man	3.18

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
STRICT	$\mathcal{R}$	Vasoconstriction factor--controls blood flow to each skin compartments.	Man	3.26
SUITA(I)		Effective thickness/conductivity for pressure suit, Btu/hr-ft-°F.	Suit	
SUBDT		Coolant temperature difference of the inlet and outlet of the sublimator, °F.	LCG	
SUBIN		Temperature of coolant into the sublimator, °F.	LCG	
SUBOUT		Temperature of coolant out of the sublimator, °F.	LCG	
SWCO2O		Mass flow rate of CO_2 out of suit; saved at the end of initial conditions, lbm/hr.	Main	
SWEAT	q_{swt}	Latent heat of total sweat production, Btu/hr.	Man	3.21
SWGOUT		Total mass flow rate of gas out of suit; saved at the end of initial condition, lbm/hr.	Main	
SWH2OO		Mass flow rate of water vapor out of suit; saved at the end of initial conditions, lbm/hr	Main	
SWTH2O		Total weight of water vapor in the cabin during postlanding saved for imposed cases, lbm.	Main	
T(I)	T_i	Temperatures of compartments, °F.	Man	3.11, A.1-A.10
TAVD		Average temperature of gas in the duct between the sublimator and the pressure suit, °F.	LCG	
TAVD2		Average temperature of gas in the duct between the LiOH bed and the sublimator in the PLSS, °F.	LCG	
TAVP		Average temperature of the coolant in the pipe between the LCG and the sublimator, °F.	LCG	
TAVP2		Average temperature of the coolant in the pipe between the sublimator and the LCG, °F.	LCG	
TAVSKIN		Average skin temperature, °F.	Man	

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
TDUCT		Average temperature of the duct between the sublimator and the suit, °F.	LCG	
TDUCT2		Average temperature of the duct between the pressure suit and the sublimator, °F.	LCG	
TEST		Compartment temperature less its set point temperature, °F.	Man	
TG(I)		Temperature of gas of each suit segment, °F.	Suit	
TGINE	$T_{gas_{in}}$	Temperature of gas into suit segment, °F.	Suit	3.39-3.40
TGOLD		Last value of temperature of gas in convergence loop, °F.	Suit	
TGOUT	$T_{gas_{out}}$	Temperature of gas out of each suit element, °F.	Suit	3.39
TGOUTS		Temperature of gas out of suit, °F.	Suit	
THX		Temperature of the sublimator, °F.	LCG	
TIME		Program time, hr.	Program	
TIS	T_{IS}	Temperature of inside of suit segment, °F.	Suit	3.43-3.44
TISAV		Average temperature of inside of suit, °F.	Suit	
TM(I)		Average temperature of undergarment/skin and inside of suit for each segment, °F.	Suit	
TMBF		Total muscle blood flow, lbm/hr.	Man	
TOS	T_{OS}	Temperature of outside of suit segment, °F.	Suit	3.40
TOSAV		Average temperature of outside of suit, °F.	Suit	
TOTCON		Total water condensed in cabin during postlanding, lbm.	Postlanding	
TOTCO2		Total CO_2 produced since EMU startup, lbm.	Suit	
TOTL		Total latent heat transfer rate, Btu/hr.	Man	
TOTLAT		Heat transfer rate by evaporation, Btu/hr.	Man	
TOTO2		Total oxygen used by crewman since EMU startup, lbm.	Suit	
TOTWCN		Total water evaporated from crewman since EMU startup, lbm.	Suit	
TPIPE		Temperature of the pipe between the LCG and the sublimator, °F.	LCG	
TPIPE2		Temperature of the pipe between the sublimator and the LCG, °F.	LCG	
TSBF		Total blood flow to skin, lbm/hr.	Man	
TSET(I)	$T_{set,i}$	Set point temperature for each man element, °F.	Man	3.19
TSKIN		Average skin temperature, °F.	Man	
TUG(I)	T_{ug}	Temperature of undergarment/skin of each segment, °F.	Man	3.37
TUGAV		Average temperature of undergarment/skin, °F.	Man	
TUGOLD		Last value of undergarment/skin temperature, calculated for each segment,	Main	

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
		in convergence loop, °F.		
TUGR		Temperature of undergarment/skin segments, °R.	Man	
TWO		Temperature of water from LCG, °F.	LCG	
TWR		Temperature of wall,°R.	Shirt	
U	U_{mech}	Rate of useful work, Btu/hr.	Man	3.8
VAPPUG	$P_{T_{ug}}$	Saturated vapor pressure at the surface of undergarment/skin, psia.	Man	3.30
VG		Velocity of gas in suit, ft/min.	Suit	
VOLC(I)	V_i	Cumulative compartment volumes of each segment, m^3.	Man	D.1-D.2
VOLHMT		Volume of helmet, ft^3.	Suit	
VPDEW	$P_{T_{dew}}$	Vapor pressure at cabin dewpoint temperature, psia.	Shirt	3.49
VPTUG	$P_{T_{ug}}$	Vapor pressure at undergarment/skin temperature, psia.	Man	3.30
VPP		FUNCTION - returns vapor pressure.	FUNCTION	
VPPCAB		Vapor pressure of cabin atmosphere, psia.	Shirt	
WARM(I)		For compartments with temperatures greater than the set point temperature, it is the temperature difference from set point; otherwise = 0.0,° °F.	Man	
WARMS		Weighted average of WARM(I) for all skin compartments, °F.	Man	
WCO2		Average mass flow rate of CO_2 in suit gas stream, lbm/hr.	Suit	
WCO2IN		Average mass flow rate of CO_2 into suit, lbm/hr.	Suit	
WCO2O		Mass flow rate of CO_2 out of suit, lbm/hr.	Suit	
WDOT1		Coolant flow rate into sublimator, lbm/hr.	LCG	
WF	$\dot{m}_{lcg}$	Total coolant flow rate in LCG, lbm/hr.	LCG	3.16
WFI		Factor for determining average mass flow rates of coolant in suit.	Suit	
WFO		Factor for determining average mass flow rates in suit.	Suit	
WG		Average mass flow rate of gas in suit, lbm/hr.	Suit	
WGE(I)	$\dot{m}_{gas}$	Average mass flow rate of gas in each suit segment, lbm/hr.	Suit	3.37,3.39
WGIN		Mass flow rate of gas into suit, lbm/hr.	Suit	
WGOUT		Mass flow rate of gas out of suit, lbm/hr.	Suit	
WH2O		Average mass flow rate of H_2O in suit, lbm/hr.	LCG	
WH2OIN		Average mass flow rate of H_2O into suit, lbm/hr.	LCG	
WH2OO		Mass flow rate of H_2O out of suit, lbm/hr.	LCG	
WN2		Average mass flow rate of nitrogen in suit, lbm/hr.	Suit	
WOLH		Average mass flow rate of H_2O out of suit heat exchanger, lbm/hr.	LCG	

Variable Name	Eng. Symbol	Definition	Type	Index (pp.)
WORK	q_{work}	Internal heat produced associated with work, Btu/hr.	Man	3.8
WO2		Average mass flow rate of oxygen in suit gas stream, lbm/hr.	Suit	
WO2IN		Average mass flow rate of oxygen into suit, lbm/hr.	Suit	
WO2OUT		Mass flow rate of O_2 out of suit, lbm/hr.	Suit	
WTCOND	$\dot{m}_{wall}$	Rate of H_2O condensation on cabin wall during postlanding, lbm/hr.	Postlanding	3.49
WTCON1	$\dot{m}_{wall}$	Rate of H_2O condensation of cabin wall during postlanding, due to free convection, lbm/hr.	Postlanding	3.49
WTFACT(I)		Body compartment weights for standard man, kg.	Man	
WTH2OA	$\dot{m}_{H_2O in}$	Rate of H_2O vapor coming into cabin during postlanding, lbm/hr.	Postlanding	3.49-3.50
WTH2OG	$\dot{m}_{H_2O prod}$	Rate of H_2O vapor generation in cabin during postlanding, lbm/hr.	Postlanding	3.49-3.50
WTH2OO	$\dot{m}_{H_2O out}$	Water vapor leaving cabin during postlanding, lbm/hr.	Postlanding	3.49-3.50

5.3 SUBROUTINE DOCUMENTATION

The subroutines are documented below according to the order of call and hierarchy. The user chooses between SUIT and SHIRT, which are of equivalent hierarchy. Subroutines SUN and SRTLCG are optional. The source language for all subroutines is FORTRAN 77.

5.3.1 Subroutine BODYSZ

- Purpose

  Subroutine BODYSZ determines for each body compartment the thermal capacitance, thermal conductance, basal metabolic rate, basal blood flow, radii and length according to the height and weight of the subject.

- Usage

  Subroutine BODYSZ communicates with the main program through common blocks (see BODYSZ listing, Appendix J) and an argument list. In particular the common block NOMO passes the input variables HEIGHT, WEIGHT and AVRM. If AVRM is set to .TRUE., the metabolic rate is adjusted according to the size of the subject, otherwise RM is assumed to be absolute and is unaltered by this subroutine. The argument list is presented below. The first column lists the BODYSZ variable names of the argument list. The second column contains the corresponding variable names in the main program and descriptions.

(Input)

MODEBZ	MODE: the operational mode.

(Input/Output)

RMBZ	RM: the metabolic rate.
ACSBZ	ACSUIT: the suit segment areas exposed to convection.
ARSBZ	ARSUIT: the suit segment areas exposed to radiation.
WSBZ	WS: the suit segment weights.

(Output)

CBZ	C: the body compartment thermal capacitances.
ACBZ	AC: the skin segment areas exposed to convection.
ARBZ	AR: the skin segment areas exposed to radiation.

The subroutine uses System Internationale units throughout--all conversions of input and output variables between the SI and English units are handled internally. Subroutine CONCYL is called exclusively by BODYSZ. CONCYL returns, for each segment, the thermal conductivities of each body compartment.

- Symbols

SWT	Body compartment weights: the core compartments of each segment are split into core skeleton and core viscera.
WTFACT	Body compartment weights of an average size man.
BFBFAC	The basal blood flow to each body compartment.
SAFACT	The percent surface area of each body segment.
CONFAC	Conversion factor: Btu/°F per KCAL/°C.
CNFAC1	Conversion factor: Btu per KCAL.
CNFAC2	Conversion factor: Btu/°F per KCAL/°C.

Subroutine BODYSZ (Concluded)

SKINL	Segment lengths of an average size man.
SKINR	Radius of each segment of an average size man.
COMSAI	Surface area of each segment of an average size man.
VOLC	Body compartment volume.
DEPTC	Length of each body segment.
RADC	Outer radius of each body compartment.
RADCM	Radius of each compartment node.
RSKINA	Body size factors for skin and suit segment surface areas.
SG	Specific gravity of subject.
SA	Total body surface area of subject.

- Method

  The method of this subroutine is covered in Appendices B, C, D and E. The general flow chart is presented in Figure 5.2.

- Accuracy

  Single-precision accuracy is used throughout this function.

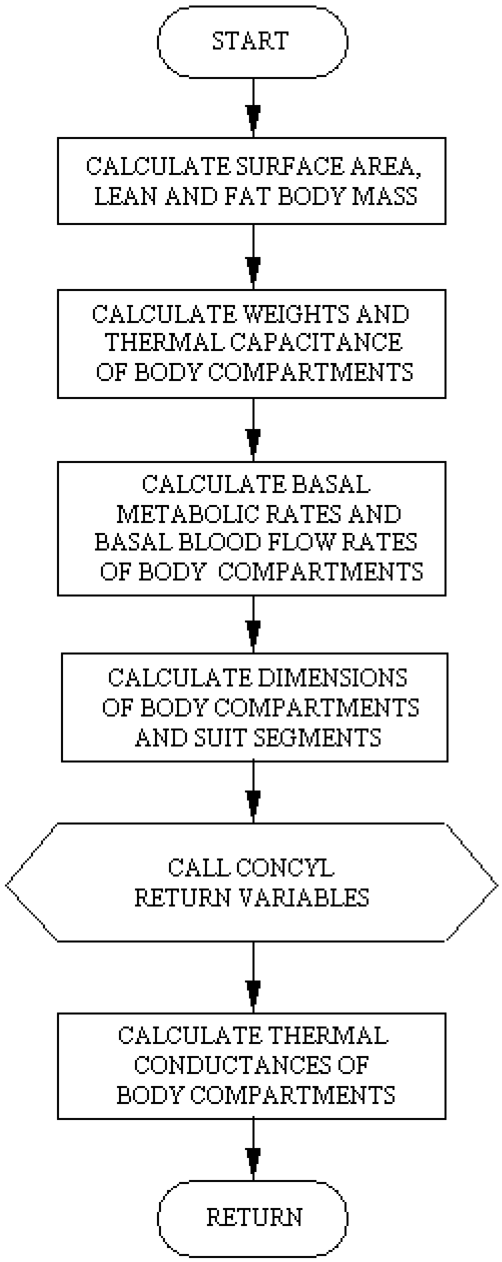


Figure 5.2 Subroutine BODYSZ General Flow Chart

5.3.2 Subroutine CONCYL

- Purpose

  Subroutine CONCYL calculates the thermal conductivities for the body compartments, and returns these values to BODYSZ.

- Usage

  Subroutine CONCYL is called one time for each body segment by subroutine BODYSZ. Each time it calculates and returns the conductivities of the four compartments through an argument list:

  (Input)

I	The body segment.
N	The core compartment of segment I.

  (Output)

CN1	The conductivity of the core compartment.
CN2	The conductivity of the muscle compartment.
CN3	The conductivity of the fat compartment.
CN4	The conductivity of the skin compartment.

- Method

  The method of this subroutine is covered in Appendix D.2. The output of the subroutine is constant, regardless of the input file to the program (a data statement could be substituted for this subroutine).

- Accuracy

  Single-precision accuracy is used throughout this subroutine.

5.3.3 Subroutine DISCON

- Purpose

  Subroutine DISCON stores the time points of the curve step changes so that subroutine CRANE can step more accurately.

- Usage

  Subroutine DISCON communicates with the main program through common blocks (see DISCON listing, Appendix J).

- Symbols

CRVL	Array of logical variables, defined in an equivalence statement in the main program.
ICRVP	Integer array, containing number of time vs. data pairs for each curve variable, defined in an equivalence statement in the main program.
NCRV	The number of curve variables.
CRVS	Array containing time vs. data points for all curve variables, defined in an equivalence statement in the main program.
I1,I.K,L X,L,M	Indexes of various DO loops.
XHATAR	Array of tested time points of the curve variables to assist CRANE in stepping more accurately
JT	Number of time points in XHATAR

Subroutine DISCON (Concluded)

- Method

  The subroutine tests each logical curve variable. If true, the subroutine then compares the consecutive time points of the CRVS array corresponding to the curve variable. If a time point differs from a previous time point by less than 6 minutes and if the time point is greater than the program time step by 6 minutes, then it is compared to each stored time point in the XHATAR array. If the time point differs by more than 1% from all stored time points, it is added in the XHATAR array.

- Restrictions

  The XHATAR array only has spaces for 50 time points. Should more than 50 be required, an error message will be displayed in the output indicating that the stepping process may be less accurate.

- Accuracy

  Single-precision accuracy is used throughout this function.

5.3.4 Subroutine ASCEND

- Purpose

  Subroutine ASCEND receives the XHATAR array of subroutine DISCON and sorts the time points into ascending values and returns the array to the main program.

- Usage

  This routine communicates with the calling program through the following argument list:

(Input)

N	The number of time points (JT) of the XHATAR array.

(Input/Output)

X	The XHATAR array.

- Symbols

I,J,K,N	Indexes of the subroutine DO loops.

- Accuracy

  Single-precision accuracy is used throughout this subroutine.

5.3.5 Subroutine SUN

- Purpose

  Subroutine SUN is an option which allows the user to calculate the intensities of solar radiation on a subject who is working or exercising outdoors in daylight. Because this calculation is dependent upon the time of day, the time of year and the surface orientation, subroutines SUN1, SUN2 and SUN3, respectively, are called exclusively by SUN to accomplish the calculation.

- Usage

  Subroutine SUN communicates with the main program through the following argument list:

Subroutine SUN (Continued)

(Input)

TZ	Time zone number (hours behind Greenwich Mean Time).
LONG	Longitude, degrees (+ West, - East).
LAT	Latitude, degrees (+ North,- South).
WT	Surface tilt angle (degrees from horizontal).
CN	Clearness number. Accounts for attenuation of radiation by smog, particles in air, etc. (conservative estimate for Houston, CN = 6)
ROG	Ground reflectivity.
CCM	Cloud cover modifier.
IDAY	Date, days (from start of year, 1-365).
ITIME	Time, hours (after midnight), (1-24).
M	Surface azimuth angle (degrees from south: +CW, -CCW) at start of iteration.
N	Surface azimuth angle (degrees from south: +CW, -CCW) at end of iteration

(Output)

AVRTOT	Average of the total solar radiation upon the surface.

For a conservative analysis, at the Johnson Space Center in Houston, TZ, LONG, LAT, CN, ROG, and CCM are given default values of 6.0, 89.0, 30.0, 1.0, 0.2, and 1.0 respectively. The SUN subroutine option is initiated by inputting ITIME at a value greater than 0.0.

- Symbols

  The internal variables used in the subroutine are covered in a Lockheed Electronics Co. technical memorandum [11].

- Method

  The subroutine is called from the main program twice. The first time M, N, and WT are set to 0.0 causing incident heat flux (Btu/hr-ft^2) to be calculated on a horizontal surface. The second time, WT is set to 90° and the surface azimuth is varied from -179° to +180° degrees. This causes the incident flux to be calculated on a series of 360 vertical surfaces. The flux is then averaged and used as the average horizontal flux on an upright cylinder. The calculations of the subroutine are described in detail elsewhere [11].

- Accuracy

  Single-precision accuracy is used throughout this function.

5.3.6 Subroutine LAGIN

- Purpose

  Subroutine LAGIN receives from the main program the value of an independent variable and returns the value of a dependent variable by interpolating curve data of the two variables using the Lagrangian method. In METMAN, the independent variable is time and the dependent variables are described in Section 4.3.

- Usage

This routine communicates with the calling program through the following argument list:

(Input)

ICODE	Code number for the call. Not used in this program except to identify the call.
T	Array name. Input curve with the independent variable and dependent variable alternating with the independent variable first.
NN	Number of point pairs in the curve.
KK	Number of points to be used in interpolation 1 or 2.
XX	Independent variable, time.

(Output)

Y	Dependent variable to be returned.

- Symbols

SUM	Same as Y, the returned dependent variable.
P	An intermediate variable in the calculation of SUM or Y.
X	Same as XX, the independent variable.
I,J,K,K2,L, M,N,N2	Indexes of various DO loops in the logic of the program.

- Method

The routine uses Lagrangian interpolation to extract a dependent variable for a given independent variable from the point pair curve. The general flow chart for this subroutine is presented in Figure 5.3.

Subroutine LAGIN (Concluded)

- Restrictions

  If two-point interpolation is used, points should be chosen to correspond with points on the curve where slopes change significantly. Three-point interpolation should be used for curves with only gradual changes in slope.

- Accuracy

  Single-precision accuracy is used throughout this subroutine.

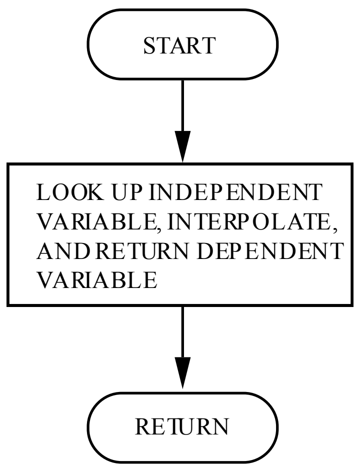


Figure 5.3 Subroutine LAGIN General Flow Chart

5.3.7 Subroutine SUIT

- Purpose

  Subroutine SUIT provides a math model describing the convection heat transfer and mass exchange between the crew member's body or undergarment and the suit gas, Subroutine SUIT, (Continued)

the radiation heat exchange between the crew member's body or undergarment and the suit, the convection heat exchange between the suit gas and the suit, the heat leak through the suit, and the heat exchange between the suit and surrounding environments.

- Usage

This subroutine is called by the Main Program and is dependent upon the associated subroutines of the METMAN program described in this document. Communication with the Main Program is through COMMON statements as shown in the program listings (see Appendix J).

- Symbols

All of the subroutine symbols are defined in Table 5.1.

- Method

The model description of this subroutine is covered in Section 3.4.2, Suited Modes. The general flow chart for this subroutine is presented in Figure 5.4A and Figure 5.4B.

- Accuracy

Single-precision accuracy is used throughout this subroutine.

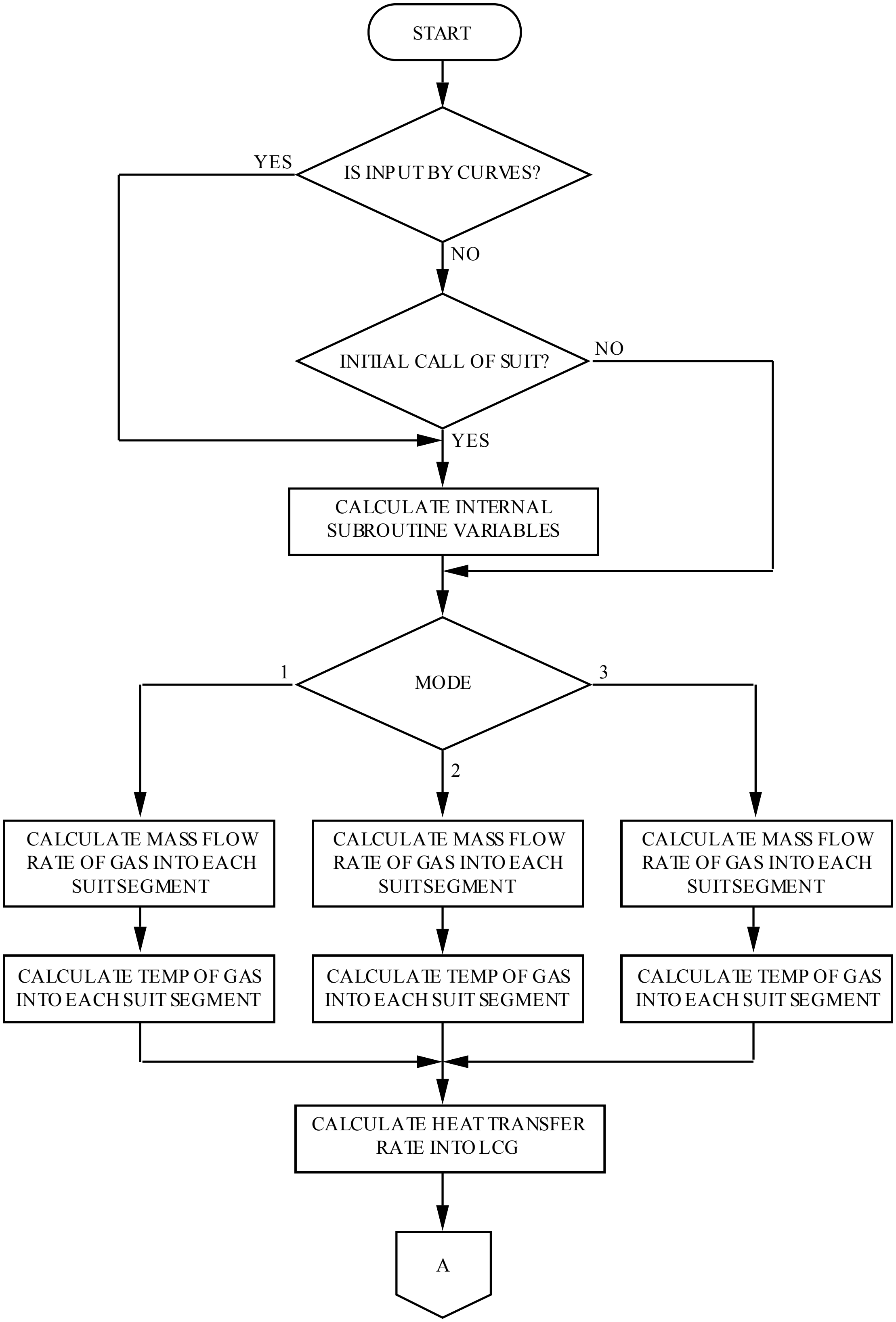


Figure 5.4A Subroutine SUIT General Flow Chart

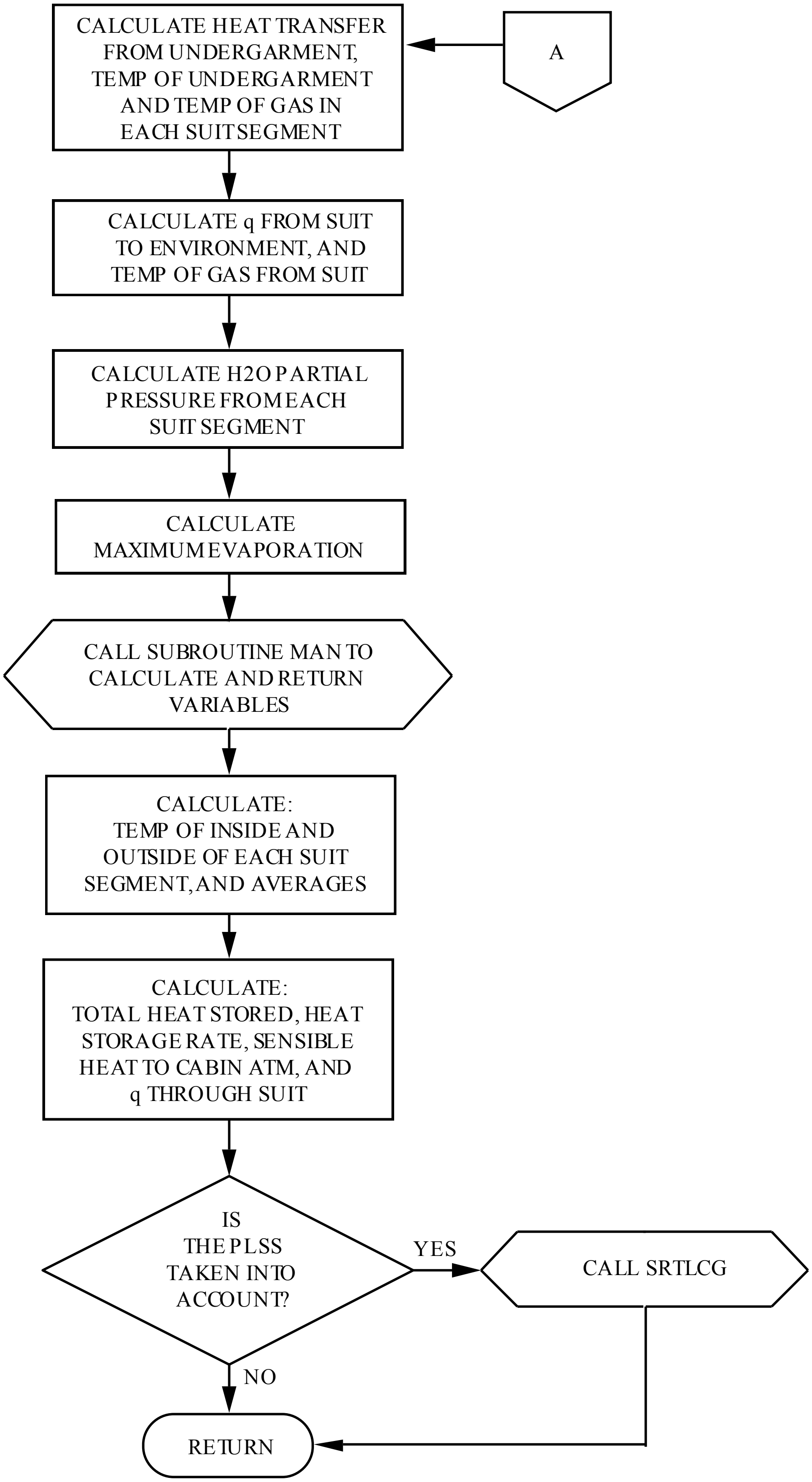


Figure 5.4B Subroutine SUIT General Flow Chart (Concluded)

5.3.8 Subroutine SHIRT

- Purpose

  Subroutine SHIRT provides a math model describing the heat and mass exchange between the crew member's body or undergarment and cabin gas, and the heat exchange between the crew member's body or undergarment and the cabin wall.

- Usage

  This subroutine is dependent on the Main Program and the associated subroutines of METMAN as covered by this document. Communication with the calling Main Program is through COMMON statements as shown by the program listings, Appendix J.

- Symbols

  All of the subroutine symbols are defined in Table 5.1.

- Method

  The model description of this subroutine is covered in Section 3.4.1, Shirt-Sleeve Mode. The general flow chart for this subroutine is presented in Figure 5.5.

- Accuracy

  Single-precision accuracy is used throughout this subroutine.

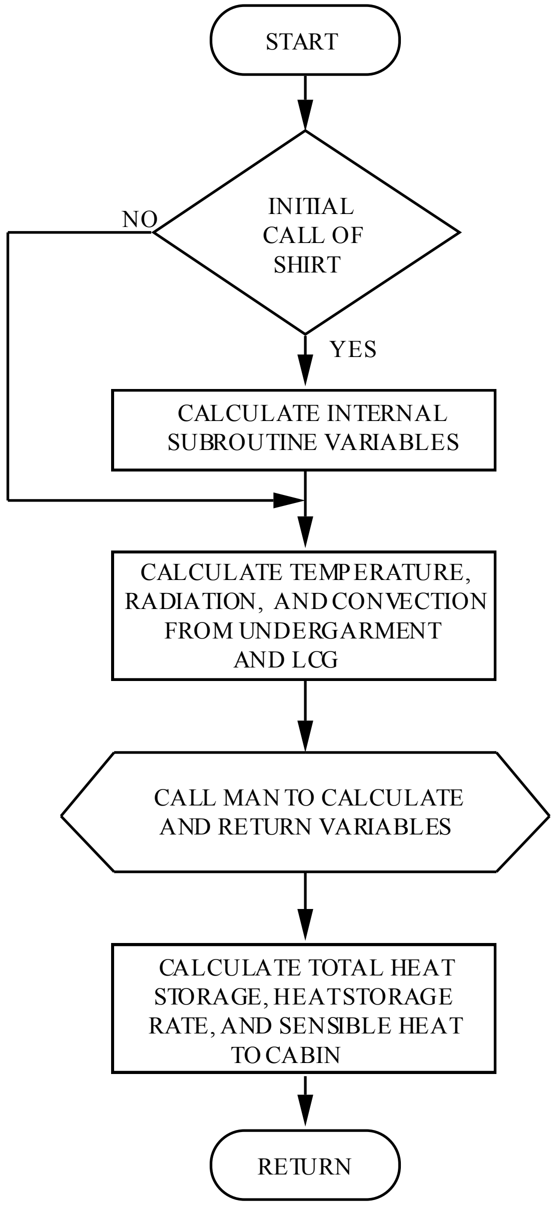


Figure 5.5 Subroutine SHIRT General Flow Chart

5.3.9 Subroutine MAN

- Purpose

  Subroutine MAN provides a math model describing the convective heat exchange of the crew member's body with its blood system, the conductive heat transfer between parts of the body, and the thermoregulatory mechanisms of the body such as sweat, shiver, and vasodilation and vasconstriction. Metabolic heat is distributed throughout the body, and useful work is calculated.

- Usage

  This subroutine is dependent upon the Main Program and the associated subroutines of the METMAN described in this document. Communication with the SUIT and SHIRT subroutines is through COMMON statements as shown in the program listings, in Appendix J.

- Symbols

  All of this subroutine's symbols are defined in Table 5.1.

- Method

  The model description of this subroutine is covered in Sections 3.1, 3.2 and 3.3 of this document. The general flow chart for Subroutine MAN is presented in Figure 5.6.

- Accuracy

  Single-precision accuracy is used throughout this subroutine.

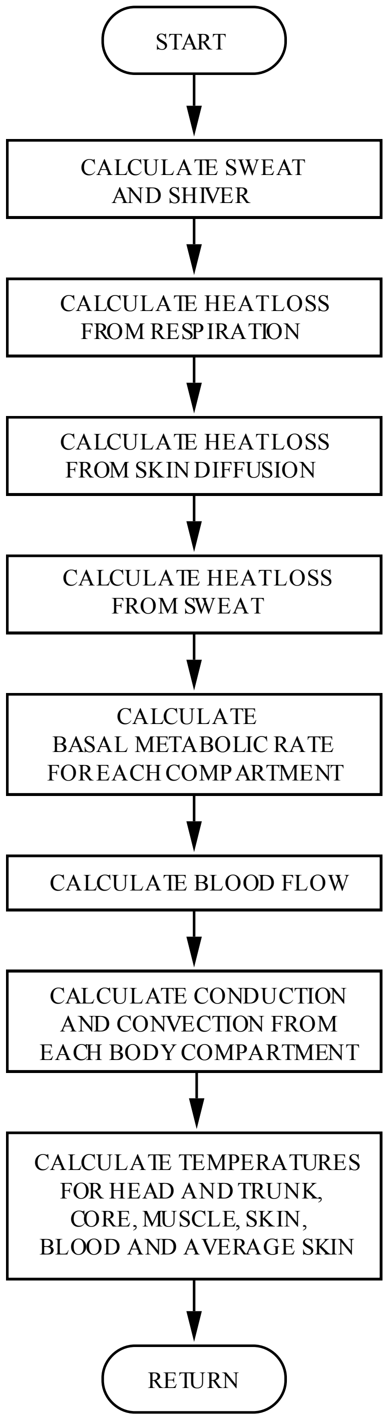


Figure 5.6 Subroutine MAN General Flow Chart

5.3.10 Subroutine CRANE

- Purpose

Subroutine CRANE simultaneously solves a system of linear differential equations using a predictor-corrector Runge-Kutta algorithm in a forward difference procedure. As applied to METMAN, the QVECT array of subroutine DERIV (see Section 5.3.11) is solved to give the nodal temperatures of the body, suit and cabin atmosphere (postlanding only).

- Usage

CRANE is called from subroutine MAN. Communication with MAN is through common block TMAT. The argument list is described in the CRANE listing, however the equivalence of four variables needs to be emphasized:

(input)

X = TIME	The independent variable.
N = NMT	The number of nodes of the system.

(input/output)

Y = T	The array of node temperatures.
F = QVECT	The array of the first derivatives of node temperatures.

- Method

The method is described and referenced in the listing (see Appendix J).

- Accuracy

All variables are single precision.

5.3.11 Subroutine DERIV

- Purpose

Subroutine DERIV assembles an array (QVECT) of the first time derivative of the node temperatures of the man, the suit and the cabin atmosphere. It also contains a postlanding simulation.

- Usage

  Subroutine DERIV is called by CRANE. Communication with CRANE and other subroutines are through common blocks. (See DERIV listing in Appendix J. Common block TMAT is described in Section 5.3.10, and the CRANE listing in Appendix J).

- Symbols

  Symbols are described in Table 5.1.

- Methods

  The heat balance equations which define the QVECT array, are described in Appendix A. A general flow chart for subroutine DERIV is presented in Figure 5.7.

- Accuracy

  All variables are single precision.

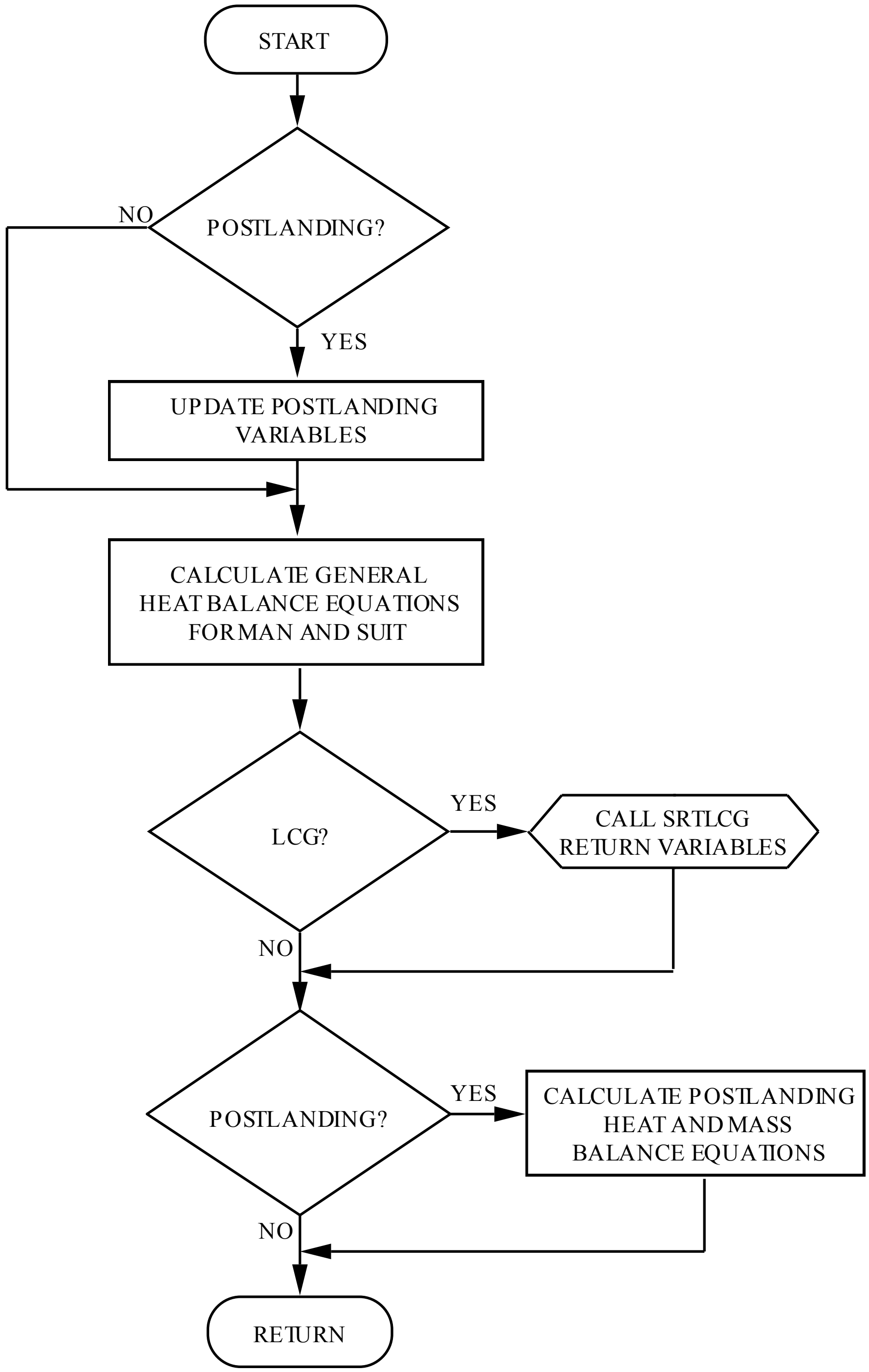


Figure 5.7 Subroutine DERIV General Flow Chart

5.3.12 Subroutine SRTLCG

- Purpose

Subroutine SRTLCG simulates the Portable Life Support System (PLSS) of the Apollo-era Extravehicular Mobility Unit (EMU) (see Figure 5.8, p. 5.65 and Figure 5.9, p. 5.66). The outlet flow conditions of the coolant from the Liquid Cooled Garment (LCG) and the oxygen from the suit are input. These are calculated in subroutines SUIT or SHIRT of the METMAN and are passed to SRTLCG through MAN and DERIV. Subroutine SRTLCG then simulates the piping and ducting of these fluids through the fan, pump, LiOH Bed, diverter valve, sublimator, pipes, and ducts of the PLSS. Heat exchange with the ducts, pipes, etc. is simulated. New inlet coolant temperatures to the LCG and oxygen temperatures to the suit are calculated as well as the updated thermal condition of the PLSS components. The new temperatures are then shunted back to SUIT or SHIRT.

- Usage

The communication of subroutine SRTLCG with subroutines DERIV is accomplished through an argument list and three COMMON blocks.

The argument list is:

(Input)

Engineering Symbol	FORTRAN	Description
$\dot{\omega}_T$	WDOT	Total coolant flow through the liquid-cooled garment, lbm/hr.
$\dot{\omega}_{sub}$	WDOT1	Flow rate of coolant through the sublimator.
c_{p_w}	CP	Specific heat of the coolant, Btu/lbm-°F.
UA_{HXS}	UASB	UA of the sublimator, Btu/hr-°F.
T_{C_1}	TSTOUT	Final liquid-cooled garment outlet temperature, °F.
$\dot{V}_G$	CFMS	Oxygen flow rate through the PLSS and suit, ft^3/min.
P_G	PG	Pressure of the gas in the suit, psia.
T_{G_0}	TGOUTS	Gas temperature into the PLSS, °F.
c_{p_g}	CPG	Specific heat (Cp) of the suit gas, Btu/lbm-°F.
q_{met}	RM	Metabolic rate, Btu/hr.
S_{H1}	SHSO	Specific humidity out of the suit, lbm H_20 vapor/lbm suit gas.

Δt	DTIME	Calculation time increment, hr.

(Output/Input From Initialization in the Main Program)

Engineering Symbol	FORTRAN	Description
T_{HX}	THX	Sublimator heat exchanger temperature, °F.
$\bar{T}_{D_1}$	TDUCT2	Average temperature of the duct between the suit and the sublimator, °F.
$\bar{T}_{D_2}$	TDUCT	Average temperature of the duct between the sublimator and the suit, °F.
$\bar{T}_{P_1}$	TPIPE	Average temperature of the pipe between the LCG and the sublimator, °F.
$\bar{T}_{P_2}$	TPIPE2	Average temperature of the pipe between the sublimator and the LCG, °F.

Subroutine SRTLCG (Continued)

(Output)

Engineering Symbol	FORTRAN	Description
T_{C_7}	TSTIN1	Inlet temperature to the LCG, °F.
T_{dew}	TDEW	Inlet dew point temperature to the suit, °F.
$T_{gas_{in}}$	TGIN	Inlet dry-bulb temperature to the suit, °F.

The three COMMON blocks are:

COMMON: FEEDWA

$\dot{m}_{H_2O}$	FDWTRR	Feed water flow rate as evaporated from sublimator, lbm/hr.

COMMON: GO

UA_{HX}	UAHX	UA of the sublimator heat exchanger,Btu/hr-°F.

COMMON: CHGTGI

$\bar{T}_{G_2}$	TAVD	Average gas temperature in the duct between the sublimator and the suit, °F.
$\underline{T}$ G1	TAVD2	Average gas temperature in the duct between the suit and the sublimator, °F.

$\underline{T}_{C2}$	TAVP	Average temperature of the coolant in the pipe between the LCG and the sublimator, °F.
$\underline{T}_{C1}$	TAVP2	Average temperature of the coolant in the pipe between the sublimator and the LCG, °F.

Subroutine SRTLCG (Continued)

- Symbols

  Besides those listed as common and in the argument list, the symbols include the following:

Engineering Symbol	FORTRAN	Description
AD2	ADUCT	Area of duct in contact with the gas between the sublimator and the suit, ft2.
AD1	ADUCT2	Area of duct in contact with the gas between the suit and the sublimator, ft2.
A_{P_1}	APIPE	Area of the pipe in contact with the coolant between the LCG and the sublimator, ft^2.
AP2	APIPE2	Area of the pipe in contact with the coolant between the sublimator and the LCG, ft2.
c_{P_D}	CPDUCT	Specific heat of the ducts, Btu/lbm-°F.
$c_{P_{HX}}$	CPHX	Specific heat of the sublimator heat exchanger, Btu/lbm-°F.
c_{P_P}	CPP	Specific heat of the pipe, Btu/lbm-°F.
cPw	CPW	Specific heat of the coolant equivalent to CPW of the main program, Btu/lbm-°F.
D_D	DE	Diameter of the ducts, ft.
D_P	DEP	Diameter of the pipes, ft.
L_D	EL	Length of the duct between the sublimator and the suit, ft.

Engineering Symbol	FORTRAN	Description
L_p	ELP	Length of the pipe between the LCG and the sublimator, ft.
L_p	ELP2	Length of the pipe between the sublimator and the LCG, ft.
L_D	EL2	Length of the duct between the suit and the sublimator, ft.
h_{D_2}	H1	Convective heat transfer coefficient between the duct and the gas in the duct between the sublimator and the suit, Btu/hr-ft^2-°F.
hP1	H1P	Convective heat transfer coefficient between the pipe and the coolant in the pipe between the LCG and the sublimator, Btu/hr-ft2-°F.
hD1	H2	Convective heat transfer coefficient between the duct and the gas in the duct between the suit and the sublimator, Btu/hr-ft2-°F.
hP2	H2P	Convective heat transfer coefficient between the pipe and the coolant in the pipe between the sublimator and the LCG, Btu/hr-ft2-°F.
ρ_{G_2}	RHO	Density of the gas in the duct between the sublimator and the suit, lbm/ft^3.
ρ_C	RHOC	Density of the coolant, lbm/ft^3.
ρ_{G_1}	RHO2	Density of the gas in the duct between the suit and the sublimator, lbm/ft^3.

Engineering Symbol	FORTRAN	Description
KAsub	SUBKA	Conductivity between the sublimator heat exchanger and the sublimation chamber, Btu/hr-°F.
$\bar{T}_{GHX}$	TAVHX	Average gas temperature in the sublimator heat exchanger, °F.
$\bar{T}_{H_2O}$	TAVH20	Temperature of the coolant in the heat exchanger of the sublimator, °F.
T_{D_2}'	TDUCT1	New temperature of the duct between the sublimator and the suit, °F.
T_{D_1}'	TDUCT2	New temperature of the duct between the suit and the sublimator, °F.
T_{DHX}'	THX1	New temperature of the heat exchanger in the sublimator, °F.
T_{P_1}'	TPIPE1	New temperature of the pipe between the LCG and the sublimator, °F.
T_{P_2}'	TPIP12	New temperature of the pipe between the sublimator and the LCG, °F.
T_{C_2}	TSBIN	Temperature of the coolant into the pump, °F.
T_{C_3}	TSBIN1	Temperature of the coolant out of the pump, °F.
T_{C_5}	TSBOUT	Temperature of the coolant out of the fan coldplate, °F.
TC6	TSTIN	Temperature of the coolant when mixed after the diverter valve and the sublimator, °F.
T_{C_4}	TSUBOT	Temperature of the coolant out of the sublimator, °F.
T_{G_1}	T1	Temperature out of the lithium hydroxide bed, °F.

Subroutine SRTLCG (Continued)

Engineering Symbol	FORTRAN	Description
$T_{G_{12}}$	T12	Gas temperature into the sublimator, °F.
T_{G_2}	T2	Gas temperature out of sublimator, °F.
T_{G_3}	T3	Gas temperature into the suit; equivalent to TGIN, °F.
UA	UAHX	Conductivity of heat exchanger in the sublimator gas side, Btu/hr-°F.
UAHXC	UAHXS	Conductivity of the heat exchanger in the sublimator, coolant side; Btu/hr-°F.
$\dot{L}_D$	VL	Velocity of gas through ducts, ft/s.
L P	VLP	Velocity of the coolant through the pipe between the LCG and the sublimator, ft/s.
L P	VLP2	Velocity of the coolant through the pipe between the sublimator and the LCG, ft/s.
$\dot{\omega}_{BP}$	WDOTBY	Sublimator coolant bypass flow rate, lbm/hr.
$\dot{\omega}_G$	WDOTG	Mass flow rate of gas through the suit, lbm/hr.
$\dot{\omega}_T$	WF	Total coolant flow rate through LCG, lbm/hr.
SH2	WGIHX	Specific humidity of water vapor out of the lithium hydroxide bed, lbm H20 vapor/lbm suit gas.
SH4	WGOD	Specific humidity of water vapor in the gas stream into the suit, lbm H20 vapor/lbm suit gas.
SH3	WGOHX	Specific humidity of the water vapor in the gas stream out of the sublimator, lbm H20 vapor/lbm suit gas.
m_{HX}	WT	Mass of the heat exchanger, lbm.

Subroutine SRTLCG (Continued)

Engineering Symbol	FORTRAN	Description
m_{D2}	WTDUCT	Mass of the duct between the sublimator and the suit, lbm.
m_{D_1}	WTDUCT2	Mass of the duct between the suit and the sublimator, lbm.
m_{P_1}	WTPIPE	Mass of the pipe between the LCG and the sublimator, lbm.
m_{P_2}	WTPIP2	Mass of the pipe between the sublimator and the LCG, lbm.

- Method

See the Symbols section for an explanation of the symbols used in the following equations.

1. First the sublimator bypass flow is calculated:

$$\dot{\omega}_{BP} = \dot{\omega}_T - \dot{\omega}_{sub}$$

2. The temperature of the coolant out of the pump is calculated by:

$$T_{C_3} = T_{C_2} + \frac{27.312}{\dot{\omega}_T}$$

3. The mass flow rate of the gas through the system is calculated by:

$$\dot{\omega}_G = \frac{\dot{V}_G\,(60)\,P_G\,(144)}{[R_G\,(T_G + 460)]}$$

4. The areas of the ducts are calculated by:

$$A_D = L_D\,D_D\,\pi$$

5. Similarly, the ares of the pipes are calculated by:

$$A_P = L_P\,D_P\,\pi$$

6. Calculate the velocity of the gas through the duct:

$$\dot{L}_D = \frac{\dot{V}}{\left(\frac{\pi D_D^2}{4}\right)}$$

7. Calculate the velocities of the coolant through the two pipes:

$$\dot{L}_P = \frac{4\,\dot{\omega}_T}{62.4\,\pi\,D_P^2}$$

8. Calculate the densities of the gas in each pipe:

$$\rho = \frac{144\ P_G}{48.3\ (\overline{T}_G + 460)}$$

9. Calculate the heat transfer coefficients between the gas and the ducts using equations for laminar flow in circular ducts (derivation is similar pp. G.5 - G.7):

$$h_D = \frac{0.02865 \left(\dfrac{\rho\ \dot{L}_D\ D_D^2\ 0.707}{0.0465\ L_D} \right)^{1/3}}{D_D}$$

10. Calculate the heat transfer coefficient between the coolant and the pipes using equations for laminar flow in circular ducts (derivation is similar to pp. G.5 - G.7):

$$h_P = \frac{0.64 \left(\dfrac{62.4\ \dot{L}_P\ D_P^2\ 0.707}{0.0465\ L_P} \right)^{1/3}}{D_P}$$

11. Calculate the temperature of the gas out of the LiOH bed:

$$T_{G_1} = T_{G_0} + \frac{0.000189\ q_{met}\ 875.0}{c_{P_G}\ \dot{\omega}_G}$$

12. Calculate the temperature of the gas into the sublimator:

$$T_{G_{12}} = T_{G_1} - (T_{G_1} - T_{D_1})\left[1 - \exp\text{-}\left(\frac{h_{D_1} A_{D_1}}{\dot{\omega}_G \, c_{p_g}}\right)\right]$$

13. Calculate the temperature of the gas out of the sublimator:

$$T_{G_2} = T_{G_{12}} - (T_{G_{12}} - T_{HX})\left[1 - \exp\text{-}\left(\frac{UA}{\dot{\omega}_G \, c_{p_g}}\right)\right]$$

14. Calculate the temperature of the gas into the suit (heat transfer through the fan is neglected):

$$T_{G_3} = T_{G_2} - (T_{G_2} - T_{D_2})\left[1 - \exp\text{-}\left(\frac{h_{D_2} A_{D_2}}{\dot{\omega}_G \, c_{p_g}}\right)\right]$$

15. Calculate the temperature of the coolant into the pump:

$$T_{C_2} = T_{C_1} - (T_{C_1} - T_{P_1})\left[1 - \exp\text{-}\left(\frac{h_{P_1} A_{P_1}}{\dot{\omega}_G \, c_{p_w}}\right)\right]$$

16. Calculate the temperature of the coolant into the sublimator out of the pump:

$$T_{C_3} = T_{C_2} + \frac{27.312}{\dot{\omega}_T}$$

17. The average water temperature in the sublimator heat exchangers is calculated as follows:

$$\overline{T}_{H_2O} = \frac{\dot{\omega}_{sub}}{UA_{HX_C}} (T_{C_3} - T_{C_4}) + T_{HX}$$

18. Calculate the temperature of the coolant out of the sublimator:

$$T_{C_4} = T_{C_3} - (T_{C_3} - T_{HX}) \left[1 - \exp\text{-}\left(\frac{UA_{HX_S}}{\dot{\omega}_{sub}\, c_{p_w}} \right) \right]$$

19. Calculate the specific humidity of water vapor in the gas into the sublimator:

$$S_{H2} = S_{H1} + \frac{0.000189\, q_{met} \left(\frac{18.02}{44.01} \right)}{\dot{\omega}_G}$$

20. The average temperature of the gas in the sublimator is then calculated as follows:

$$\overline{T}_{GHX} = T_{HX} - \frac{\dot{\omega}_G\, c_{p_g}}{UA} (T_{G_2} - T_{G_{12}})$$

21. The specific humidity of water vapor out of the sublimator is defined as follows:

$$S_{H3} = \frac{18.0\, P_{sat_3}}{32.0\, P_G}$$

22. Next the new temperature of the heat exchanger is calculated as follows:

$$T'_{HX} = \frac{\Delta t}{m_{HX}\, cp_{HX}} \left[UA\,(\overline{T}_{GHX} - T_{HX}) + 1040\,\dot{\omega}_G\,(S_{H2} - S_{H3}) + UA_{HXS}\,(\overline{T}_{H_2O} - T_{HX}) - KA_{sub}\,(T_{HX} - 32.0) \right] + T_{HX}$$

23. The specific humidity of the water vapor into the suit is defined as follows:

$$S_{H4} = \frac{18.0\, P_{sat_4}}{32.0\, P_G}$$

24. Now calculate the average temperature of the gas in the duct between the sublimator and the suit:

$$\overline{T}_{G_2} = T_{D_2} - \frac{\dot{\omega}_G\, c_{p_g}}{h_{D_2}\, A_{D_2}}\,(T_{G_3} - T_{G_2})$$

25. Similarly calculate the average temperature of the gas in the duct between the suit and the sublimator:

$$\overline{T}_{G_1} = T_{D_1} - \frac{\dot{\omega}_G\, c_{p_g}}{h_{D_1}\, A_{D_1}}\,(T_{G_{12}} - T_{G_1})$$

26. Calculate the new temperature of the duct between the sublimator and the suit as follows (assume ducts are insulated):

$$T'_{D\,2} = \frac{\Delta t}{m_{D_2}\, cp_D} \left[h_{D_2}\, A_{D_2}\,(\overline{T}_{G_2} - T_{D_2}) + 1040\,\dot{\omega}_G\,(S_{H2} - S_{H3}) \right] + T_{D_2}$$

27. Similarly calculate the new temperature of the duct between the suit and the sublimator:

$$T'_{D1} = \frac{\Delta t}{m_{D1}\, c_{P_D}} \left[h_{D1}\, A_{D1} (\bar{T}_{G1} - T_{D1})\right] + T_{D1}$$

28. Set the old values of the ducts sublimator heat exchanger and gas temperature to the new:

$$T_{D2} = T'_{D2}$$

$$T_{D1} = T'_{D1}$$

$$T_{HX} = T'_{HX}$$

$$T_{dew} = T_{G3}$$

$$T_{gas_{in}} = T_{G3}$$

29. Calculate the coolant temperature out of the fan coldplate:

$$T_{C5} = T_{C4} + \frac{70.5}{\dot{\omega}_{sub}}$$

30. The temperature of the coolant as it mixes from the diverter value flow is calculated as follows:

$$T_{C6} = \frac{\dot{\omega}_{BP}\, T_{C3} + \dot{\omega}_{sub}\, T_{C5}}{\dot{\omega}_T}$$

Subroutine SRTLCG (Continued)

31. Calculate the temperature of the coolant into the LCG as follows:

$$T_{C7} = T_{C6} - (T_{C6} - T_{P2}) \left[1 - \exp\text{-}\left(\frac{h_{P2}\, A_{P2}}{\dot{\omega}_T\, c_p} \right) \right]$$

32. Calculate the average temperature of the coolant in the pipe between the LCG and the sublimator as follows:

$$\overline{T}_{C_1} = T_{P_1} - \frac{\dot{\omega}_T \, c_{p_w}}{h_{P_1} \, A_{P_1}} (T_{C_2} - T_{C_1})$$

33. Similarly, the average temperature between the sublimator and the LCG is calculated as follows:

$$\overline{T}_{C_2} = T_{P_2} - \frac{\dot{\omega}_T \, c_{p_w}}{h_{P_2} \, A_{P_2}} (T_{C_7} - T_{C_6})$$

34. Then calculate the new pipe temperature between the LCG and the sublimator (assume pipes are insulated):

$$T'_{P\,1} = \frac{\Delta t}{m_{P_1} \, c_{P_P}} \left[h_{P_1} \, A_{P_1} (\overline{T}_{C_1} - T_{P_1})\right] + T_{P_1}$$

35. Then calculate the new pipe temperature between the sublimator and the LCG.

$$T'_{P\,2} = \frac{\Delta t}{m_{P_2} \, c_{P_P}} \left[h_{P_2} \, A_{P_2} (\overline{T}_{C_2} - T_{P_2})\right] + T_{P_2}$$

Subroutine SRTLCG (Continued)

36. Calculate the old pipe temperatures by setting them equal to the new:

$$T_{P_1} = T'_{P\,1}$$

$$T_{P_2} = T'_{P\,2}$$

37. Calculate the feed water use rate as follows:

$$\dot{m}_{H_2O} = \frac{KA_{sub}\,(T_{HX} - 32)}{1040}$$

There is an alternate way of calculating the inlet coolant temperature without taking into account the thermal exchange to the pipes. This method follows:

1. First, the sublimator bypass flow rate is calculated as described before:

$$\dot{\omega}_{BP} = \dot{\omega}_{T} - \dot{\omega}_{sub}$$

2. Calculate the temperature inlet of the sublimator as follows:

$$T_{C_3} = T_{C_1} + \frac{27.312}{\dot{\omega}_T}$$

3. The coolant temperature of the sublimator outlet is calculated as follows:

$$T_{C_4} = \exp\left[\ln(T_{C_3}) - \frac{UA_{HX}}{\dot{\omega}_{sub}}\right] + 32$$

Subroutine SRTLCG (Continued)

4. Next calculate the temperature out of the fan:

$$T_{C_5} = T_{C_4} + \frac{70.5}{\dot{\omega}_{sub}\, c_{p_g}}$$

5. The temperatures of the suit inlet are then calculated:

$$T_{C_7} = \frac{\dot{\omega}_{BP}\, T_{C_3} + \dot{\omega}_{sub}\, T_{C_5}}{\dot{\omega}_T}$$

- Restrictions

  Units of flow must be in lbm/hr, specific heat in Btu/lbm-°F, UA in Btu/hr-°F, and temperature in °F.

- Accuracy

  Single-precision accuracy is used throughout this subroutine.

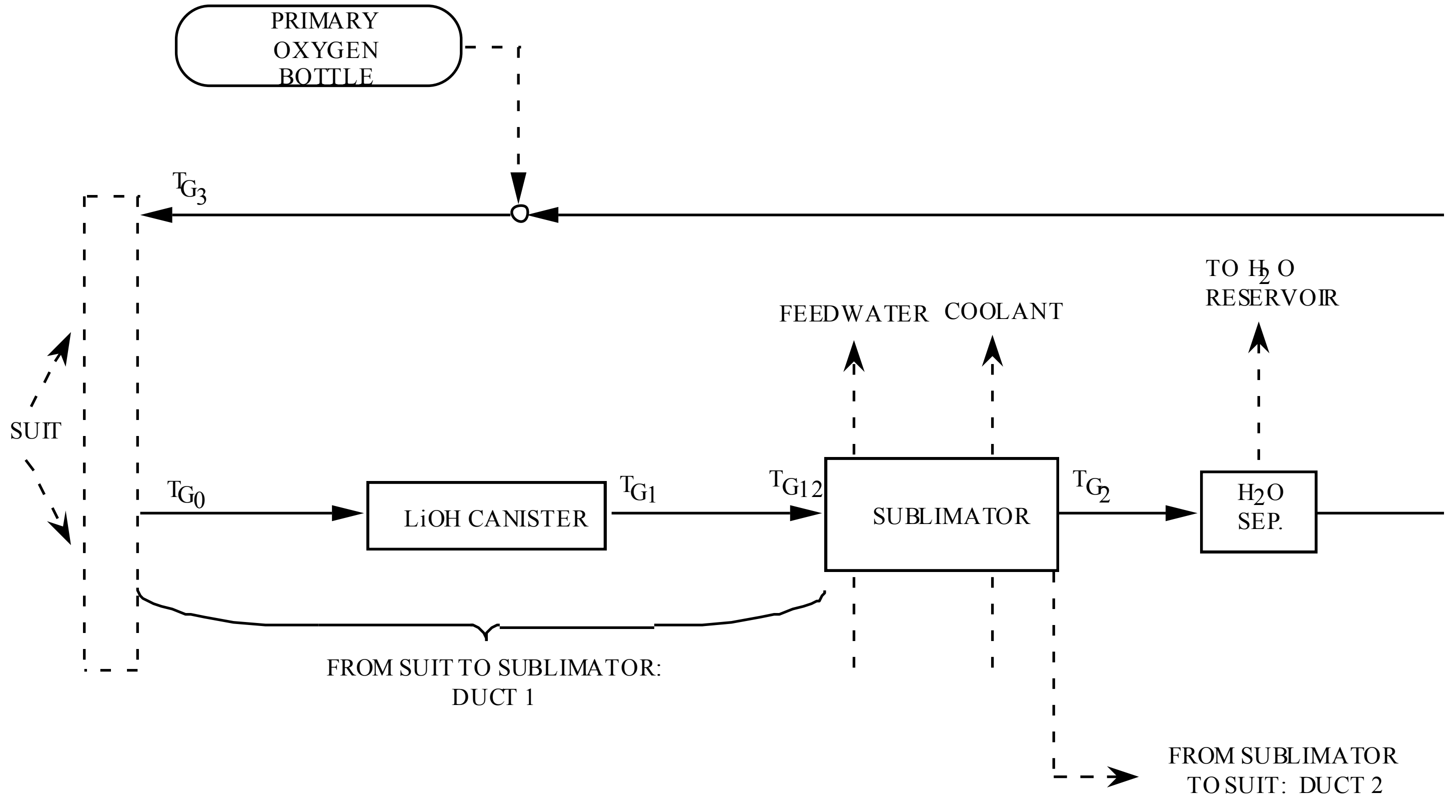


Figure 5.8 Model of PLSS Ventilation Loop in SRTLCG

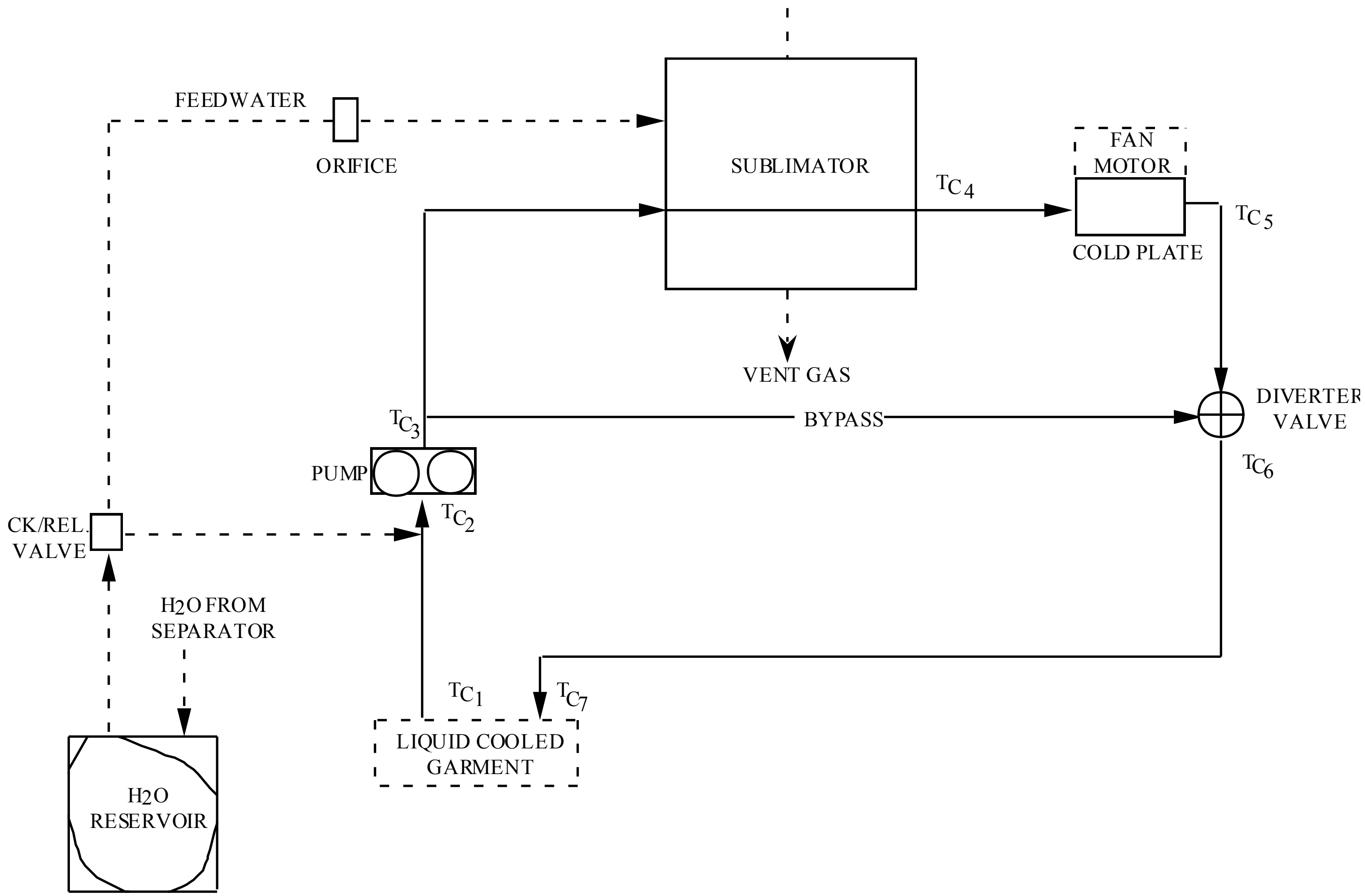


Figure 5.9 Model of PLSS Coolant Loop in SRTLCG

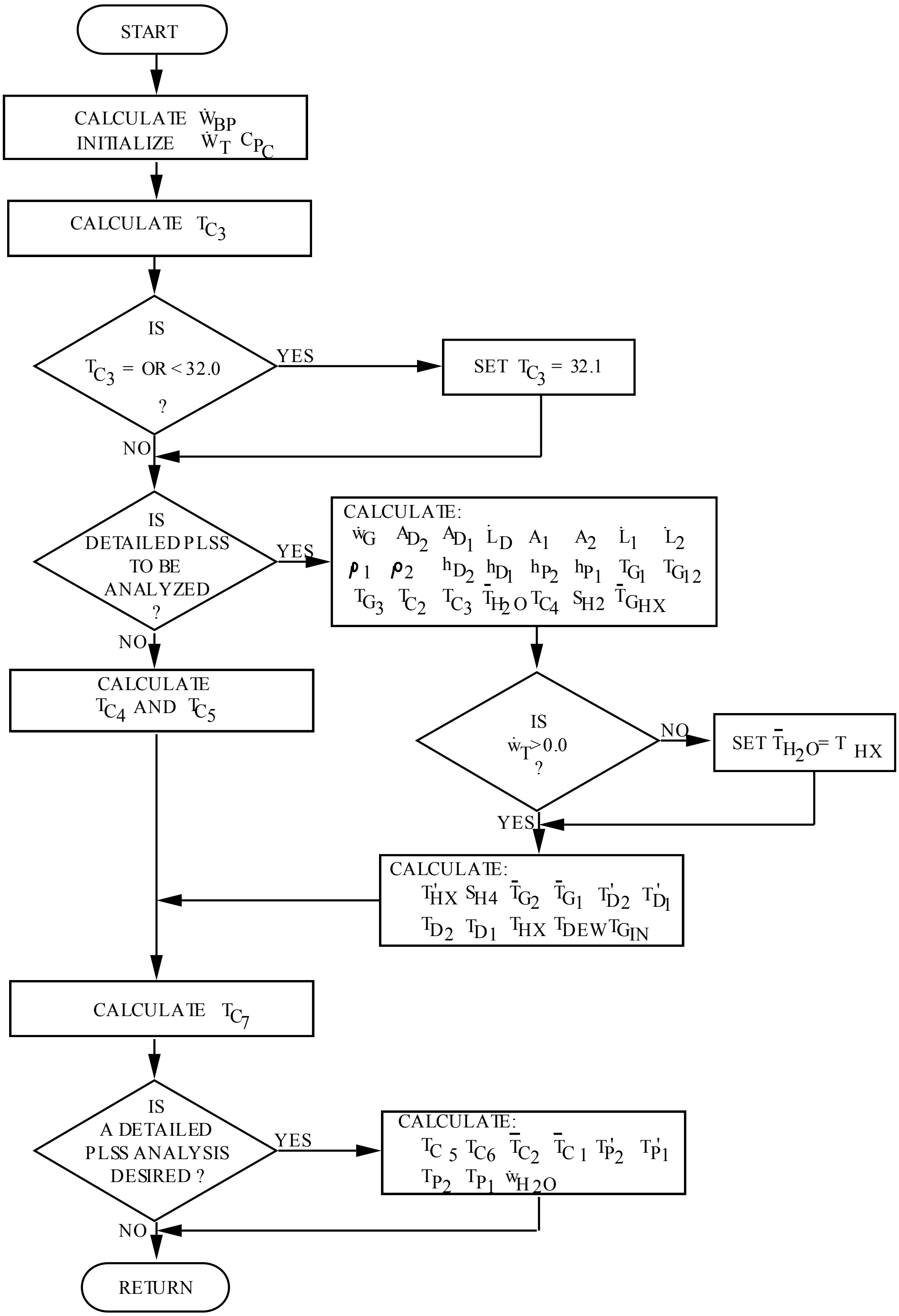


Figure 5.10 Subroutine SRTLCG Flow Chart

5.3.13 Subroutines TMATRX and MINDVP

These subroutines have been commented out of the program. They were used to solve the QVECT array (subroutine DERIV) when conditions were near steady state. TMATRX and MINDVP are no longer used because subroutine CRANE is more accurate.

5.4 FUNCTION DOCUMENTATION

5.4.1 Function DEWPT

- Purpose

  The function DEWPT returns a temperature of saturation in degrees Fahrenheit for a given water vapor pressure in millimeters of mercury.

- Usage

  The argument list consists of one variable:

  PMMHG The partial pressure of water vapor, mm Hg.

- Symbols

  DEWPT Dew point of gas/water vapor mixture, °F.

  DEWPTR $= \dfrac{0.110516 \times 10^5}{20.0455 - \ln(P)}$, the dew point in °R.

  F $= -0.00004286517$

Function DEWPT (Continued)

  G $= 0.001626943 \text{ PLOG} + 0.03533457$

  H $= -0.07086745 \text{ PLOG}^2 - \text{PLOG} - 2.519124$

P	Water vapor partial pressure converted to units of psia.
PINHG	Water vapor partial pressure converted to units of inches Hg.
PLOG	Natural logarithm of PINHG.

- Method

The dew point is correlated from

For $P \leq 0.0$: $DEWPT = 0.0$

For $0.0 < P < 0.0185$: $DEWPT = DEWPTR - 459.67$

For $0.0185 \leq P$: $DEWPT = -\dfrac{G + [G^2 - 4\,(F)\,(H)]^{1/2}}{2\,F}$

- Restrictions

Input is in mm Hg, and output is in degrees Fahrenheit.

- Accuracy

Single-precision accuracy is used throughout this function.

5.4.2 Function VPP

- Purpose

  Function VPP returns the saturated water vapor pressure in psia for a temperature in degrees Fahrenheit.

- Usage

  This function has one argument:

T	Temperature converted from °F to °R, for internal calculations.

- Symbols

T	Temperature in degrees Fahrenheit at which saturated water vapor pressure is desired.
TSAVE	Storage for T so that the initial value of T is passed back to the program
VPP	Saturated vapor pressure to be returned to calling statement at the temperature specified in the calling argument.
F	$= -0.07086745$
G	$= 0.001626943\,(T + 459.67) - 1.0$
H	$= -0.00004286517\,(T + 459.67)^2 + 0.003633457\,(T + 459.67) - 2.519124$

Subroutine VPP (Continued)

- Method

  For $T < 0.0$: $VPP = 0.0$

  For $0.0 < T < 300$: $VPP = \exp\left(15.2670 - \dfrac{8392.28}{T + 459.67}\right)$

  For $300 < T$: $VPP = 0.4912 \exp\left\{\dfrac{-G - [G^2 - 4 (F)(H)]^{1/2}}{2F}\right\}$

- Restrictions

  Temperature must be in degrees Fahrenheit. Pressure returned will be in psia.

- Accuracy

  Single-precision accuracy is used throughout this function.

6 REFERENCES

The following is a list of primary references for this document. Additional references, pertaining to supplemental information, are presented at the end of each appendix.

1. Nguyen, N. H., "Shuttle EMU Comfort as Affected by Body Size," Technical Memorandum, Lockheed Engineering and Management Services Co., LEMSCO-14567 (March 1980).

2. Stolwijk, J. A. J., "A Mathematical Model of Physiological Temperature Regulation in Man," NASA CR-1855, (August 1971).

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4. Cook, D. W., Nguyen, N. H., "Liquid Cooled Garment Overall Heat Transfer Coefficient Definition," Technical Memorandum, Lockheed Engineering and Management Services Company, LEMSCO-15410 (August 1980).

5. Fanger, P. O., Thermal Comfort, McGraw-Hill, New York (1970).

6. Lin, S. H. and Berenson, P. J., " Study of the Thermal Processes for Man in Space," AiResearch Manufacturing Co., NASA CR-216 (1965).

7. Inouye, J., Hick, F. K., Tesler, S. E., and Keetan, R. W., "Effect of relative humidity on heat loss of men exposed to environments of 80, 76, and 72°F," ASRAE Trans., Vol. 59 (1953), p. 329.

8. Kerslake, D. M. "Errors Arising from the Use of Mean Heat Exchange Coefficients in the Calculation of the Heat Exchanges of a Cylindrical Body in a Transverse Wind." Temperature, Vol. 3 , Biology and Medicine, J. D. Hardy (Ed.), New York: Reinhold (1963), pp. 183-190.

9. Nguyen, N. H., Hu, A. S., "Body Size Effect on Shuttle EMU Comfort Curves," Technical Memorandum, Lockheed Engineering and Management Services Company, LEMSCO-16363, (March 1981).

10. Cook, D. W., and Nguyen, N. H., "Shirt Sleeve Comfort as Affected by Body Size," Lockheed Electronics Company, LEC-13401 (May 1979)

11. Cook, D. W., "Addition of the Solar Effect Option to the 41-Node Man Program," Technical Memorandum, Lockheed Electronics Co., LEC-10195 (March 1977).

APPENDIX A

HEAT TRANSFER EQUATIONS OF THE BODY COMPARTMENTS

The purpose of this appendix is to present and define the heat transfer equations for each body compartment. Average temperature equations for the skin and muscle layers are included. The body compartment equations are adapted from the first derivative heat balance equations that are solved by the model simultaneously using a forward-difference algorithm (see Section 5.3.10, subroutine CRANE and Section 5.3.11, subroutine DERIV).

A.1 BODY COMPARTMENT SUBSCRIPTS

Throughout this appendix a scheme of subscripts is adopted. Numeric subscripts from 1 to 41 are used with i-type variables. Each subscript refers to a distinct body compartment (see Table A.1). Note that these subscripts correspond to array indices of the FORTRAN variables in the METMAN source code.

Table A.1
Body Compartment Subscript Designation

Body Segment	Core	Muscle	Fat	Skin
	Body Compartment Designation (i)			
Head	1	2	3	4
Trunk	5	6	7	8
Right Arm	9	10	11	12
Left Arm	13	14	15	16
Right Leg	17	18	19	20
Left Leg	21	22	23	24
Right Hand	25	26	27	28
Left Hand	29	30	31	32
Right Foot	33	34	35	36
Left Foot	37	38	39	40
	Central Blood		41	

AVERAGE TEMPERATURE SUBSCRIPTS

Skin	42
Muscle	43

A.2 TEMPERATURES OF THE CORE COMPARTMENTS

A.2.1 Temperatures of the Head Core

$$T_1 = T_1 + \frac{dt}{C_1}(q_{met,1} + q_{conv,1} - q_{cond,1} - q_{rsen,1} - q_{lat,1})$$

where:

$$q_{met,1} = q_{BMR,1}$$

$$q_{conv,1} = \dot{m}_{basal,1}\,(T_{41} - T_1)$$

$$q_{cond,1} = K_1\,(T_1 - T_2)$$

$$q_{rsen,1} = 0.771\ q_{rsen}$$

$$q_{lat,1} = 0.771\ q_{rlat}$$

A.2.2 Temperatures of the Trunk Core

$$T_5 = T_5 + \frac{dt}{C_5}(q_{met,5} + q_{conv,5} - q_{cond,5} - q_{rsen,5} - q_{lat,5})$$

where:

$$q_{met,5} = q_{BMR,5}$$

$$q_{conv,5} = \dot{m}_{basal,5}\,(T_{41} - T_5)$$

$$q_{cond,5} = K_5\,(T_5 - T_6)$$

$$q_{rsen,5} = 0.476\ q_{rsen}$$

$$q_{lat,5} = 0.476\ q_{rlat}$$

A.2.3 Temperatures of the Remaining Core Compartments (i = 9, 13, 17 ..,37)

$$T_i = T_i + \frac{dt}{C_i}(q_{met,i} + q_{conv,i} - q_{cond,i})$$

where:

$$q_{met,i} = q_{BMR,i}$$

$$q_{conv,i} = \dot{m}_{basal,i}\,(T_{41} - T_i)$$

$$q_{cond,i} = K_i\,(T_i - T_{i+1})$$

A.3 TEMPERATURES OF THE MUSCLE COMPARTMENTS

A.3.1 Temperatures of the Head Muscle

$$T_2 = T_2 + \frac{dt}{C_2}(q_{met,2} + q_{conv,2} + q_{cond,1} - q_{cond,2} - q_{rsen,2} - q_{lat,2})$$

where:

$$q_{met,2} = q_{BMR,2} + q_{mshiv,2}$$

$$q_{conv,2} = \dot{m}_{basal,2}(T_{41} - T_2)$$

$$q_{cond,1} = K_1(T_1 - T_2)$$

$$q_{cond,2} = K_2(T_2 - T_3)$$

$$q_{rsen,2} = 0.172\, q_{rsen}$$

$$q_{lat,2} = 0.172\, q_{rlat}$$

A.3.2 Temperatures of the Trunk Muscle

$$T_6 = T_6 + \frac{dt}{C_6}(q_{met,6} + q_{conv,6} + q_{cond,5} - q_{cond,6} - q_{rsen,6} - q_{lat,6})$$

where:

$$q_{met,6} = q_{BMR,6} + q_{mshiv,6} + q_{mwork,6}$$

$$q_{conv,6} = \dot{m}_{basal,6}(T_{41} - T_6)$$

$$q_{cond,5} = K_5(T_5 - T_6)$$

$$q_{cond,6} = K_6(T_6 - T_7)$$

$$q_{rsen,6} = 0.523\, q_{rsen}$$

$$q_{lat,6} = 0.523\, q_{rlat}$$

A.3.3 Temperatures of the Remaining Muscles Compartments (i = 10,14,18,...,38)

$$T_i = T_i + \frac{dt}{C_i} \left(q_{met,i} + q_{conv,i} + q_{cond,i\text{-}1} - q_{cond,i}\right)$$

where:

$$q_{met,i} = q_{BMR,i} + q_{mshiv,i} + q_{mwork,i}$$

$$q_{conv,i} = \dot{m}_{basal,i} \left(T_{41} - T_i\right)$$

$$q_{cond,i\text{-}1} = K_{i\text{-}1} \left(T_{i\text{-}1} - T_i\right)$$

$$q_{cond,i} = K_i \left(T_i - T_{i+1}\right)$$

A.4 TEMPERATURES OF THE FAT COMPARTMENTS

A.4.1 Temperatures of the Head Fat

$$T_3 = T_3 + \frac{dt}{C_3}(q_{met,3} + q_{conv,3} + q_{cond,2} - q_{cond,3} - q_{rsen,3} - q_{lat,3})$$

where:

$$q_{met,3} = q_{BMR,3}$$

$$q_{conv,3} = \dot{m}_{basal,3}(T_{41} - T_3)$$

$$q_{cond,2} = K_2(T_2 - T_3)$$

$$q_{cond,3} = K_3(T_3 - T_4)$$

$$q_{rsen,3} = 0.0574\ q_{rsen}$$

$$q_{lat,3} = 0.0574\ q_{rlat}$$

A.4.2 Temperatures of the Remaining Fat Compartments (i = 7,11,15,...,39)

$$T_i = T_i + \frac{dt}{C_i}(q_{met,i} + q_{conv,i} + q_{cond,i-1} - q_{cond,i})$$

where:

$$q_{met,i} = q_{BMR,i}$$

$$q_{conv,i} = \dot{m}_{basal,i}(T_{41} - T_i)$$

$$q_{cond,i-1} = K_{i-1}(T_{i-1} - T_i)$$

$$q_{cond,i} = K_i(T_i - T_{i+1})$$

A.5 TEMPERATURES OF THE SKIN COMPARTMENTS

$$T_i = T_i + \frac{dt}{C_i}(q_{met,i} + q_{conv,i} + q_{cond,i-1} - q_{senc,i} - q_{lat,i} - q_{rad,i} - q_{lcg,i})$$

where:

$$q_{met,i} = q_{BMR,i}$$

$$q_{conv,i} = \dot{m}_{basal,i}\,(T_{41} - T_i)$$

$$q_{cond,i-1} = K_{i-1}\,(T_{i-1} - T_i)$$

$$q_{senc,i} = h_i\,(T_{ug,i} - \overline{T}_{gas,i})$$

$$q_{lat,i} = q_{swt,i} + q_{dif,i}$$

$$q_{rad,i} = A_{R,i}\,\sigma\,\mathcal{F}_i\,[(T_{ug,i} + 460.0)^4 - (T_{IS,i} + 460.0)^4]$$

$$q_{lcg,i} = f_i\,\dot{m}_{lcg,i}\,c_p\,(1.0 - e^{-\eta_i})\,(T_{av} - T_{inlet})$$

A.6 TEMPERATURE OF THE CENTRAL BLOOD

$$T_{41} = T_{41} + \frac{dt}{C_{41}}\,q_{conv}$$

where:

$$q_{conv} = \sum_{i=0}^{40} q_{conv,i} \qquad \text{(Btu/hr)}$$

A.7 AVERAGE SKIN AND MUSCLE TEMPERATURE

A.7.1 Average Skin Temperature

$$T_{42} = 0.07\ T_{4} + 0.3602\ T_{8} + 0.06705\ T_{12} + 0.06705\ T_{16} + 0.1587\ T_{20} + 0.1587\ T_{24} + 0.025\ T_{28} + 0.025\ T_{32} + 0.0343\ T_{36} + 0.0343\ T_{40}$$

A.7.2 Average Muscle Temperature

$$T_{43} = 0.02325\ T_{2} + 0.549\ T_{6} + 0.0527\ T_{10} + 0.0527\ T_{14} + 0.1592\ T_{18} + 0.1592\ T_{22} + 0.00115\ T_{26} + 0.00115\ T_{30} + 0.00115\ T_{34} + 0.00115\ T_{38}$$

APPENDIX B

NOMOGRAPHIC AND ANTHROPOMETRIC RELATIONS

B.1 CALCULATION OF BODY SURFACE AREA

The body surface area (in SI units) is calculated from a nomographic relationship [1] :

$$A = 3.209\ M^{0.45}\ H^{0.725} \qquad (cm^2)$$

where M is the body weight in kg and H is the height in cm. The surface area is distributed to the skin compartments according to Table B.1.

Table B.1
Distribution of Body Surface Area
Among the Skin Compartments

Skin Compartments	Distribution Factor
Head	0.7000
Trunk	0.3602
Arms	0.1341
Legs	0.3174
Hands	0.0500
Feet	0.0686
	1.0003

These segment areas are used for all calculations involving skin area. However, in the case of radiation in the shirt-sleeve mode these areas are reduced by a factor of 0.795. This factor helps account for radiant exchange of the body with itself.

B.2 CALCULATION OF FAT BODY MASS AND LEAN BODY MASS

In order to calculate the weight of a body segment or compartment, given M and H, it is necessary to predict the mass of the body that is fat tissue (M_f) and the mass of the body which is not fat tissue (M_l). These are given by the following formulae [2]:

$$M_f = M \left\{ \left[\frac{5.548}{0.8 \left(\frac{H^{0.242}}{M^{0.1}} \right) + 0.162} \right] - 5.044 \right\} \qquad \text{(kg)}$$

and

$$M_l = M - M_f \qquad \text{(kg)}$$

B.3 CALCULATION OF BODY COMPARTMENT WEIGHTS

Body compartment weights (M_i) are determined using the following formulae [3,4,5]:

$$M_i = K_m M_l \qquad \text{(kg)}$$

for core, muscle and skin nodes and

$$M_i = K_m M_f \qquad \text{(kg)}$$

for fat nodes, where the values of the weight distribution coefficient, K_m, are defined in Table B.2 for each node.

Table B.2

Values of Weight Distribution Coefficient, K_m

	Values of K_m				
Segments	Core Skeleton	Core Viscera	Muscle	Fat	Skin
Head	0.0192920	0.0282320	0.005880	0.033300	0.00423
Trunk	0.0470400	0.1870400	0.283400	0.633300	0.02130
Arm	0.0118780	0.0058820	0.026640	0.043350	0.00382
Leg	0.0395840	0.0151760	0.080500	0.106650	0.00947
Hand	0.0018240	0.0002352	0.000594	0.006665	0.00147
Foot	0.0029242	0.0004706	0.000594	0.010000	0.00188

The total core mass, muscle mass and skin mass are:

$$M_c = 0.4354\, M_l \qquad \text{(kg)}$$

$$M_m = 0.5058\, M_l \qquad \text{(kg)}$$

$$M_s = 0.0588\, M_l \qquad \text{(kg)}$$

The mass of the fat layer, M_f, has already been defined.

B.4 REFERENCES

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APPENDIX C

CALCULATION OF BASAL METABOLIC AND BASAL BLOOD FLOW RATES

C.1 CALCULATION OF BASAL METABOLIC RATE

The total basal metabolic rate, q_{BMR}, has been defined in Section 3.2.1, Heat Generation. It is equal to the sum of the basal metabolic rate of each tissue layer:

$$q_{BMR} = q_c + q_m + q_f + q_s \qquad \text{(Kcal/hr)}$$

where q_c, q_m, q_f, and q_s are the total basal metabolic rates of the core, muscle, and skin and fat layers, respectively, which are determined by

$$q_c = 0.10\, q_{BMR}'\, A \qquad \text{(Kcal/hr)}$$

$$q_m = 0.18\, q_{BMR}'\, A \qquad \text{(Kcal/hr)}$$

$$q_f = 0.30\, M_f \qquad \text{(Kcal/hr)}$$

$$q_s = 0.30\, M_s \qquad \text{(Kcal/hr)}$$

and q_{BMR}' is 38.76 Kcal/hr-m^2, A is the surface area of the body, and M_f and M_s are the masses of the fat and skin layers defined in Appendix B. The basal metabolic rate is distributed among the body compartments according to the following equations [1]:

$$q_{c,i} = q_c \frac{M_{c,i}}{M_c} \qquad \text{(Kcal/hr)}$$

$$q_{m,i} = q_m \frac{M_{m,i}}{M_m} \qquad \text{(Kcal/hr)}$$

$$q_{f,i} = 0.3\, M_{f,i} \qquad \text{(Kcal/hr)}$$

$$q_{s,i} = 0.3\, M_{s,i} \qquad \text{(Kcal/hr)}$$

except for the core compartments of the head and trunk [2]:

$$q_{c,head} = q_c \frac{M_{c,head}}{M_c} + 0.16\, q_{BMR}'\, A \qquad \text{(Kcal/hr)}$$

$$q_{c,trunk} = q_c \frac{M_{c,trunk}}{M_c} + 0.56\, q_{BMR}'\, A \qquad \text{(Kcal/hr)}$$

C.2 CALCULATION OF BASAL BLOOD FLOW RATES

The formula for basal blood flow rates in the skin nodes is [3]:

$$\dot{m}_{s,i} = F_{BF}\, M_{s,i} \qquad \text{(liters/hr)}$$

where F_{BF} is an empirically determined blood flow factor for each skin node, listed below in Table C.1.

Table C.1
Skin Blood Flow Factor, FBF

Skin Compartments	F_{BF}
Head	5.34
Trunk	1.56
Arms	1.35
Legs	0.84
Hands	5.58
Feet	2.34

For the core compartments of the head [1] and trunk [4] the blood flow rates are essentially constant:

$$\dot{m}_{c,head} = 45 \qquad \text{(liters/hr)}$$

$$\dot{m}_{c,trunk} = 210 \qquad \text{(liters/hr)}$$

The blood flow rates for all other core, muscle and fat nodes are [1]:

$$\dot{m}_{other} = 1.2\, q_{BMR,i} \qquad \text{(liters/hr)}$$

C.3 REFERENCES

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APPENDIX D

INTERNODAL CONDUCTANCE CALCULATIONS

D.1 CALCULATION OF COMPARTMENT GEOMETRY

Each body segment is modeled as a composite cylinder consisting of four concentric tissues, that is, a core cylinder with three cylindrical shells (muscle, fat and skin). The geometry of each segment can therefore be described with a cylindrical length, l_j, and the outermost radial dimension of each compartment, r_c, r_m, r_f, and r_s. These data are derived from the surface area of each segment, A_j (see Appendix A.1), and the volume of each compartment [1]. The compartment volume, V, for the purposes of finding the outermost radii, is the volume of the compartment of interest plus all contained compartments, e.g. the fat compartment volume is the volume of the fat, muscle and core compartments. For each segment, the compartment volumes are calculated from the cumulative compartment weights with the assumption of a specific volume of 1000 cm^3/kg:

$$V_c = 1000\, M_c \qquad (cm^3)$$

$$V_m = 1000\, (M_c + M_m) \qquad (cm^3)$$

$$V_f = 1000\, (M_c + M_m + M_f) \qquad (cm^3)$$

$$V_s = 1000\, (M_c + M_m + M_f + M_s) \qquad (cm^3)$$

Thus, for each segment, j:

$$l_j = \frac{A_j^2}{4\pi V_s} \qquad \text{(cm)}$$

and for each tissue compartment, i, of segment, j:

$$r_i = \left(\frac{V_i}{\pi l_j}\right)^{1/2} \qquad \text{(cm)}$$

The nodal radii of the compartments ($r_{n,c}$, $r_{n,m}$, $r_{n,f}$ and $r_{n,s}$) are taken as the geometric midpoint between the inner and outer compartment boundaries.

D.2 CALCULATION OF COMPARTMENT CONDUCTIVITIES

Because thermal conductivity is a material property, it should be independent of body size. Internodal conductances for this model have been determined in experiments on human subjects [2]. These conductances, and compartment radii data for a standard man [3] are used to determine the conductivities of each compartment. The general internodal conductance equation for two concentric cylinders is the reciprocal of the sum of the thermal resistance between the inner node and the boundary and the thermal resistance between the boundary and the outer node:

$$G_j^{i \to i+1} = \frac{2\ \text{š}\ l_j}{\dfrac{\ln\left(\dfrac{r_i}{r_{n,i}}\right)}{g_i} + \dfrac{\ln\left(\dfrac{r_{n,i+1}}{r_i}\right)}{g_{i+1}}} \qquad \text{(Kcal/hr–°C)}$$

Where $G_j^{i->i+1}$ is the conductance between compartments i and i+1 of segment j, and g_i and g_{i+1} are the conductivities of compartment i and i+1, respectively (see Figure D.1). Because the conductivities of skin and fat are approximately equal [4], the above equation can be rearranged to solve for the conductivity of the skin and fat for a particular segment:

$$g_s \;=\; g_f \;=\; \frac{G_j^{f\rightarrow s}\left(\ln\left(\frac{r_f}{r_{n,f}}\right) + \ln\left(\frac{r_{n,s}}{r_f}\right)\right)}{2\ \check{s}\ l_j} \qquad \text{(Kcal/hr–°C–cm)}$$

The conductivity of fat, g_f, can then be used with the same equation to solve for the muscle conductivity, g_m. After rearranging:

$$g_m \;=\; \frac{\ln\left(\frac{r_m}{r_{n,m}}\right)}{\left\{\left[\frac{2\ \check{s}\ l_j}{G_j^{m\rightarrow f}}\right] - \left[\frac{\ln\left(\frac{r_{n,f}}{r_m}\right)}{g_f}\right]\right\}} \qquad \text{(Kcal/hr–°C–cm)}$$

Similarly, this form of the equation is used with g_m to determine the value of g_c. The values of the conductivities for each compartment thus calculated are listed in Table D.1.

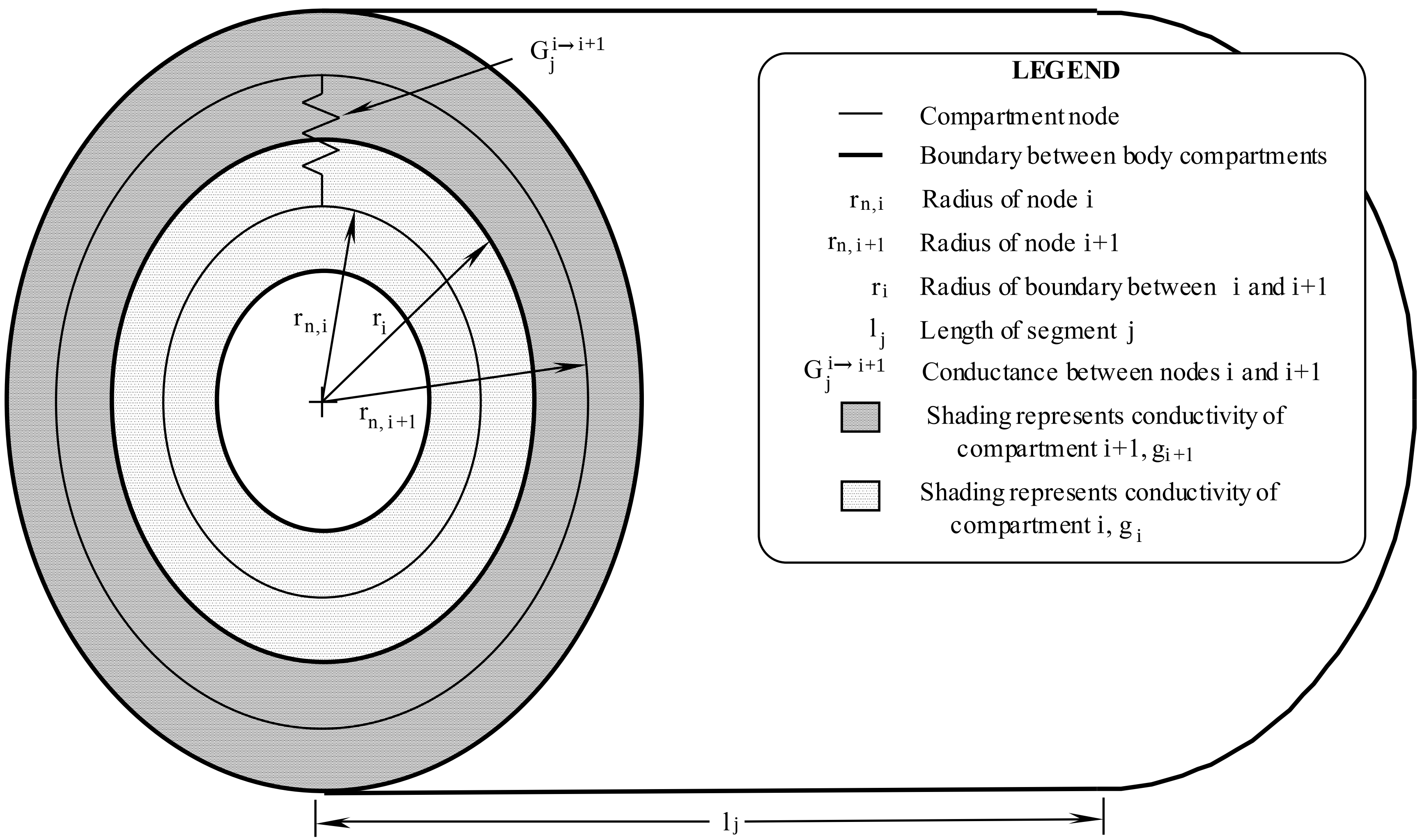

Figure D.1 Radial Conductance Between Two Body Compartments

Table D.1

Body Compartment Thermal Conductivities

Body Segment	Kcal/hr-°C-cm (1 x 10^3)			
	Core	Muscle	Fat	Skin
Head	6.9372	0.3240	0.5567	0.5567
Trunk	0.6908	0.5971	0.3328	0.3328
Arm	1.9634	1.2954	0.6961	0.6961
Leg	1.5683	1.8182	0.4451	0.4451
Hand	1.7426	0.3752	0.6049	0.6049
Foot	1.3390	0.4347	0.5501	0.5501

D.3 CALCULATION OF INTERNODAL CONDUCTANCES

Using the compartment conductivities of Table D.1 the internodal conductances are calculated according to the general conductivity formula, repeated again for clarity:

$$G_j^{i \to i+1} = \frac{2\,\check{s}\,l_j}{\dfrac{\ln\left(\dfrac{r_i}{r_{n,i}}\right)}{g_i} + \dfrac{\ln\left(\dfrac{r_{n,i+1}}{r_i}\right)}{g_{i+1}}} \qquad \text{(Kcal/hr–°C)}$$

where the standard man data for radii and l_j are not used but rather refer to those of the simulated subject, adjusted for body size according to Section D.1 above [1].

D.4 REFERENCES

1. Nguyen, N. H., "Shuttle EMU Comfort as Affected by Body Size," Technical Memorandum, Lockheed Engineering and Management Services Co., LEMSCO- 14567 (March 1980).

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APPENDIX E

CORRELATION OF TOTAL LCG HEAT TRANSFER COEFFICIENT TO LATENT HEAT LOAD

E.1 IMPROVED LCG UA CORRELATION

Prior to August 1980, METMAN used a third degree polynomial of the inlet LCG temperature to determine the total LCG heat transfer coefficient [1,2]. Since then, a new relationship between the total LCG UA and the latent heat load has been established (see Figure E.1) through a series of nine physiological experiments with three subjects [3]. The LCG UA was observed to change with metabolic rate even when flow rate and inlet temperature were held constant. Because the component UAs for the tube and coolant are constant for flow rates under 240 lbm/hr, the observed changes in total LCG UA reflect changes in the component UA between the skin and the tube [4]. These changes are reasonable since at higher latent loads, increased sweating and muscle swelling would be expected to increase the contact conductance of the skin and the tube. With this new correlation, METMAN was shown to predict the total LCG UA more accurately [3].

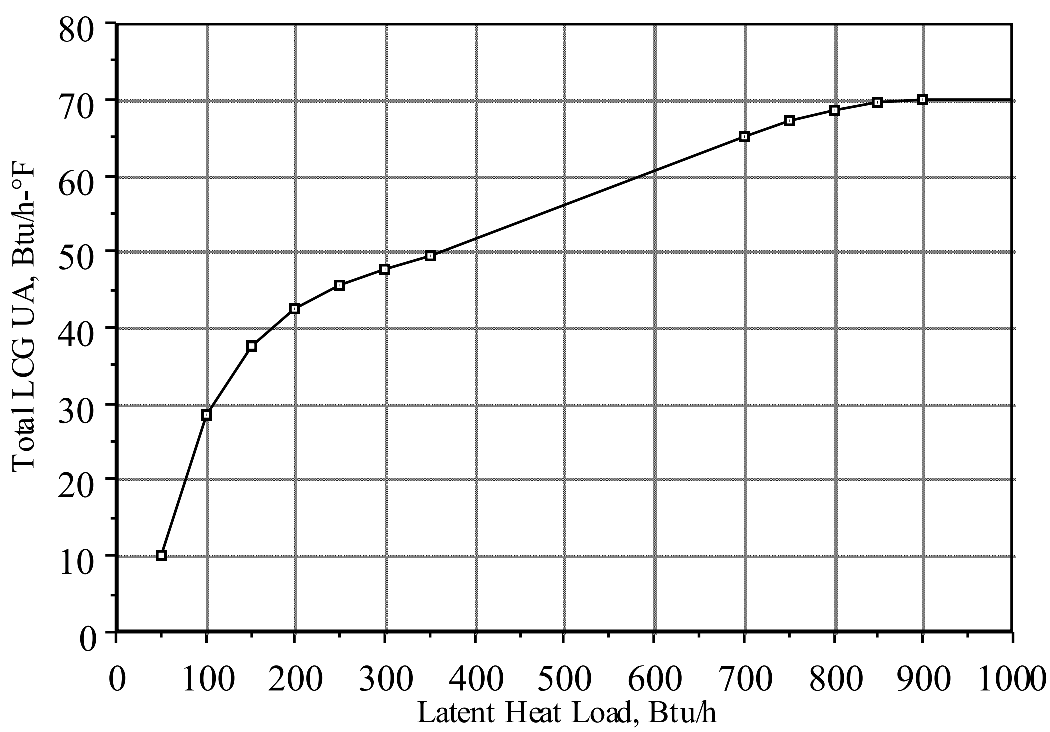

Figure E.1 Total LCG UA vs. Latent Heat Load

Figure 6.1Total LCG UA vs. Latent Heat Load

E.2 REFERENCES

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APPENDIX F

CALCULATION OF THERMAL CAPACITANCE

F.1 CALCULATION OF THERMAL CAPACITANCE

The thermal capacitance, C_i, is the product of body compartment weight (see Appendix B.3) and specific heat. The specific heats used for skeleton, fat and other tissues have been experimentally determined [1] and are presented in Table F.1.

Table F.1

Specific Heats of Tissues

	(Kcal/kg-°C)
Skeleton	0.5
Fat	0.6
All Other	0.9

Because the mass of the core is modeled as part skeleton and part viscera, the thermal capacitance of a core compartment i is:

$$C_{c,i} = 0.5\, M_{skel,i} + 0.9\, M_{visc,i} \qquad \text{(Kcal/°C)}$$

The thermal capacitances of the muscle, fat and skin compartments are:

$$C_{m,i+1} = 0.9\, M_{m,i+1} \qquad \text{(Kcal/°C)}$$

$$C_{f,i+2} = 0.6\, M_{f,i+2} \qquad \text{(Kcal/°C)}$$

$$C_{s,i+3} = 0.9\ M_{s,i+3} \qquad \text{(Kcal/°C)}$$

The central blood compartment consists of approximately 2.5 liters of blood, contained in the heart and large thoracic vessels, which amounts to a thermal capacitance of 2.25 Kcal/°C. Because the thermal capacitance of this compartment is located within the trunk core, it is subtracted from the thermal capacitance of the trunk core:

$$C_{c,trunk} = (0.5\ M_{skel} + 0.9\ M_{visc})_{trunk} - 2.25 \qquad \text{(Kcal/°C)}$$

F.2 REFERENCES

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APPENDIX G

DERIVATION OF CONVECTION COEFFICIENTS

G.1 SHIRT-SLEEVE MODE CONVECTION COEFFICIENTS

If gravitational force is non-zero, both free and forced convection can occur in the shirt-sleeve mode. The model computes the convection coefficients for both cases and uses whichever is greater to calculate the convection heat transfer.

G.1.1 Forced Convection

The average Nusselt number, $\overline{Nu}_d$, a dimensionless heat transfer correlation, has been developed from a large mass of empirical data obtained with many gases and liquids. For conditions of laminar flow perpendicular to a cylinder [1]:

$$\overline{Nu}_d = \frac{\bar{h}\, d}{k} = C\, Re^m\, Pr^{1/3}$$

where $\bar{h}$ is the average convection coefficient, d is the cylinder diameter, k is the thermal conductivity of the gas and Re and Pr are the Reynolds and Prandtl numbers. For laminar flow conditions where Re > 100, C = 0.6 and m = 1/2, giving:

$$\bar{h} = 0.6 \frac{k}{d} \, Pr^{1/3} \, Re^{1/2} \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

substituting for Re:

$$\bar{h} = 0.6 \frac{k}{d} \, Pr^{1/3} \left(\frac{V \, d \, \rho}{\mu} \right)^{1/2} \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

where V, ρ and μ are the velocity, density and dynamic viscosity of the fluid, respectively. Assuming the gas to behave ideally, ρ can be substituted with $\frac{P_{cab}}{R\,T}$, and after rearranging:

$$\bar{h} = 0.6 \, k \, Pr^{1/3} \left(\frac{V_{cab} \, P_{cab}}{\mu \, d \, R \, T} \right)^{1/2} \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

Approximating the body as a cylinder 1 ft in diameter and assuming the following properties for air at 80 °F:

T	= 540	(°R)
k	= 0.01516	(Btu/hr-ft-°R)
Pr	= 0.720	
μ	= 0.04374	(lbm/ft-hr)
R	= 53.34	(ft-lbf/lbm-°R)

Substituting these values yields the final relation [2]:

$$\bar{h} = 0.212 \left(V_{cab}\, P_{cab} \right)^{1/2} \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

where V_{cab} has units of ft/min and P_{cab} has units of psia. This relation is accurate to within 10% for all breathable mixtures of oxygen and nitrogen. It is applied to each body segment in the model using the following equation [3]:

$$\bar{h}_j = \bar{h}\ \kappa_1 \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

where, for each segment , κ_1 corrects for the d = 1 ft assumption and is equal to $\left(\frac{1}{2\ r_s}\right)^{1/2}$; r_s is the radius of each segment at the boundary of the skin and the environment (see Appendix D.1). In the suited modes, this convection coefficient is also used with the outside suit surface, except that the correction term, κ_4, accounts for the increased cylinder size and is equal to $\left(\frac{1 + 0.222}{2\ r_s + 0.222}\right)^{1/2}$.

G.1.2 Free Convection

For laminar flow conditions, the Nusselt number for free convection with a vertical plate is [4]:

$$\overline{Nu}_l = \frac{\bar{h}\, l}{k} = 0.67 \left(\frac{Pr^2\ Gr}{0.952\ +\ Pr} \right)^{1/4}$$

where l is the vertical length of the plate, and Gr is the Grashof number. Substituting air properties at 80 °F of Pr = 0.720 and k = 0.01516 Btu/hr-ft-°R, and rearranging:

$$\bar{h} = 0.00753 \frac{1}{l}\ \ Gr^{1/4} \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

Substituting for Gr:

$$\bar{h} = 0.00753 \frac{1}{l} \left[\frac{g\, \beta\, l^3\, \rho^2\, |T_s - T_\infty|}{\mu^2} \right]^{1/4} \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

where g is the local gravitational force, β is the expansion coefficient, T_s is the surface temperature of the plate and T_∞ is the free stream temperature of the air. Substituting $g = 32.2\ G$, where G is the ratio of the local gravitational field to that of sea level (32.2 ft/s^2), $\beta = \frac{1}{T}$ (for a perfect gas) , $\rho = 144 \frac{P_{cab}}{R\, T_{cab}}$, where P_{cab} is in psia, and rearranging yields:

$$\bar{h} = 0.215 \left[\frac{g_r\, P_{cab} |T_s - T_\infty|}{l\, R^2\, T^3\, \mu^2} \right]^{1/4} \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

Finally, substitute the following air properties at 80°F:

$$T = 540 \qquad (°R)$$

$$\mu = 1.241 \times 10^{-5} \qquad \text{(lbm/ft-s)}$$

$$R = 53.34 \qquad \text{(ft-lbf/lbm-°R)}$$

and let:

$$T_s = T_{ug} \qquad (°F)$$

$$T_\infty = T_{cab} \qquad (°F)$$

$$l = 3.5 \qquad \text{(ft)}$$

which gives:

$$\bar{h} = 0.06 \left[G\, P_{cab}^2\, |T_{ug} - T_{cab}| \right]^{1/4} \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

Again, this equation is applied to each body segment using factors to correct for $l = 3.5$ ft:

$$\bar{h}_j = \bar{h}\ \kappa_2 \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

where κ_2 is equal to $\left(\frac{3.5}{l_j}\right)^{1/4}$ and l_j is the segment length defined in Appendix D.1.

G.2 CONVECTION COEFFICIENTS FOR SUITED MODES

The Nusselt number relation used in the suited case for derivation of the convection coefficient is based on laminar flow in circular ducts and a combined entry length (velocity and thermal profiles begin undeveloped) [5]:

$$\overline{Nu}_d = \frac{\bar{h}\,d}{k} = 1.86\left(\frac{d\ Re\ Pr}{l}\right)^{1/3}\left(\frac{\mu}{\mu_s}\right)^{0.14}$$

The viscosity ratio $\frac{\mu}{\mu_s}$ is approximately 1.0 because the temperature differences of the gas in the suit are always small:

$$\bar{h} = 1.86\,\frac{k}{d}\left(\frac{d\ Re\ Pr}{l}\right)^{1/3} \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

substituting for $Re = \frac{V\,d\,\rho}{\mu} = \frac{\dot{m}_{gas}\,d}{\mu\,A}$, where $\dot{m}_{gas}$ is the mass flow rate of the gas and A is the cross sectional area of the duct:

$$\bar{h} = 1.86\,\frac{k}{d}\left(\frac{\dot{m}_{gas}\,d^2\,Pr}{\mu\,l\,A}\right)^{1/3} \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

Based on the dimensions and ducting configuration of the Gemini suit [2], substitute the average values:

$d = 0.222$ (ft)

$l = 3.5$ (ft)

$A = 0.196$ (ft^2)

where d is twice the clearance between the man and the suit wall, l is the inlet to outlet distance, and A is the duct area (annular cross-section), and substitute the gas properties of air at 90 °F:

$\mu = 0.0453$ (lbm/ft-hr)

$Pr = 0.707$

$k = 0.0154$ (Btu/hr-ft-°F)

which yields:

$$\bar{h} = 0.134\, \dot{m}_{gas}^{1/3} \qquad (\text{Btu/hr-ft}^2\text{-°F})$$

The coefficient is corrected to reflect the appropriate ducting length of each segment:

$$\bar{h}_j = \bar{h}\ \kappa_3 \qquad \text{(Btu/hr-ft}^2\text{-°F)}$$

where $\kappa_3 = \left(\frac{l}{l_j}\right)^{1/3}$.

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APPENDIX H

DERIVATION OF MASS TRANSFER COEFFICIENTS

In every case, the mass transfer coefficients are derived by applying the heat-mass transfer analogy [1]. That is, for each set of fluid dynamic conditions, the equation for the Sherwood number (dimensionless concentration gradient at a surface) can be obtained by replacing the Prandtl numbers with Schmidt numbers in the corresponding Nusselt number relationship (pertinent Nusselt number relationships are presented in Appendix G). The mass transfer coefficient can then be derived directly from these equations. The mass transfer coefficients are used to calculate E_{max}, the maximum evaporative capacity of skin assuming the surface is fully wetted.

H.1 SHIRT-SLEEVE MODE MASS TRANSFER COEFFICIENTS

As with convection coefficients, the mass transfer coefficients are determined for both forced and free conditions, and the model uses whichever is greater in the calculation of E_{max}.

H.1.1 Forced Convection Conditions

For laminar flow perpendicular to a cylinder, a Nusselt number relation has been determined [2]:

$$\overline{Nu}_d = \frac{\overline{h}_D\, d}{k} = 0.6\ Re^{0.500}\ Pr^{0.333}$$

Applying the mass transfer analogy, the corresponding Sherwood number for these conditions is [3]:

$$\overline{Sh}_d = \frac{\overline{h}_D\, d}{D} = 0.6\ Re^{0.500}\ Sc^{0.333}$$

or:

$$\overline{Sh}_d = \frac{\bar{h}_D\, d}{D} = 0.6 \left(\frac{V\, \rho\, d}{\mu}\right)^{0.500} \left(\frac{\mu}{\rho\, D}\right)^{0.333}$$

where D is the diffusion coefficient for water vapor in air:

$$D = \frac{12.7}{P} \left(\frac{T}{460}\right)^{1.81} \quad (\text{ft}^2/\text{hr})$$

Substituting for D, and letting $\rho = \dfrac{144\, P_{cab}}{R\, T}$ gives:

$$\bar{h}_D = 0.355 \left(\frac{V_{cab}}{P_{cab}\, d}\right)^{0.500} \left(\frac{1}{\mu\, R}\right)^{0.167} T^{1.04} \quad (\text{ft/hr})$$

where V_{cab} has units of ft/min and P_{cab} has units of psia. Assuming d is 1 ft, letting $T = T_{cab}$ and using properties of air at 70 °F:

μ = 0.04374 (lbm/ft-hr)

R = 53.34 (ft-lbf/lbm-°R)

yields:

$$\bar{h}_D = 0.308 \left(\frac{V_{cab}}{P_{cab}}\right)^{0.5} (T_{cab} + 460)^{1.04} \qquad \text{(ft/hr)}$$

This coefficient is used with each body segment by correcting for the 1 ft diameter assumption:

$$\bar{h}_{D,j} = \bar{h}_D \, \kappa_1 \ \text{(ft/hr)}$$

where $\kappa_1 = \left(\frac{d}{2\ r_s}\right)^{0.5}$.

The maximum evaporative capacity, E_{max} , is defined for each segment as:

$$E_{max} = \bar{h}_{D,j} \, A_C \, V_{effm} \frac{h_{fg}}{R\ T_{gas}} (P_{Tug} - P_{Tdew}) \quad \text{(Btu/hr)}$$

Substituting water vapor properties at 70 °F:

$T = 530$ (°R)

$R = 85.76$ (ft-lbf/lbm-°R)

$h_{fg} = 1054$ (Btu/lbm)

and substituting for $\bar{h}_{D,j}$ yields:

$$E_{max} = 0.126 \, \kappa_1 \, A_C \, V_{effm} \left(\frac{V_{cab}}{P_{cab}}\right)^{0.5} (T_{cab} + 460)^{1.04} (P_{Tug} - P_{Tdew}) \qquad \text{(Btu/hr)}$$

H.1.2 Free Convection Conditions

The Nusselt relation for laminar flow on a vertical plate is [1]:

$$\overline{Nu}_l = \frac{\bar{h}\, l}{k} = 0.67 \left(\frac{Pr^2\, Gr}{0.952 + Pr} \right)^{1/4}$$

The analogous Sherwood relation is [2]:

$$\overline{Sh}_l = \frac{\bar{h}_D\, l}{D} = 0.67 \left(\frac{Sc^2\, Gr}{0.952 + Sc} \right)^{1/4}$$

or rearranging to give the mass transfer coefficient:

$$\bar{h}_D = 0.67\, \frac{D}{l} \left(\frac{Sc^2\, Gr}{0.952 + Sc} \right)^{1/4} \qquad \text{(ft/hr)}$$

where D is the diffusion coefficient:

$$D = \frac{12.7}{P} \left(\frac{T}{460} \right)^{1.81} = 0.0002045\, \frac{T^{1.81}}{P} \qquad \text{(ft}^2\text{/hr)}$$

Substituting $\mu = 0.04374$ lbm/ft-hr, $\rho = \dfrac{144\, P}{R\, T}$, T = 540 °R and D into the Schmidt number gives:

$$Sc = \frac{\mu}{\rho\, D} = 0.516$$

Substituting this value into the equation for the mass transfer coefficient gives:

$$\bar{h}_D = 0.0137 \frac{T}{l\,P}\, Gr^{0.25} \qquad \text{(ft/hr)}$$

The Grashof number is defined in Appendix G.2.2 as:

$$Gr = \frac{g\, l^3\, \rho}{\mu^2} \left[\rho\, \beta\, (T_s - T_\infty)\right]$$

However, free convection with heat and mass transfer is complicated by the effect of the water vapor on the density difference [1]. Therefore, modifying the term in the brackets and letting $\beta = \frac{1}{T}$ yields:

$$Gr = \frac{g\, l^3\, \rho}{\mu^2} \left[\rho \frac{(T_s - T_\infty)}{T} + \Delta\rho_{H_2O} \left(\frac{R_{H_2O}}{R} - 1\right)\right]$$

Substituting:

T	=	540 (°R)	
g	=	32.2 G	(ft/s^2)
ρ	=	the density of dry air	(ft^3/lbm)
$\Delta\rho_{H_2O}$	=	the difference in water vapor density of the skin surface and the freestream gas	(ft^3/lbm)
R_{H_2O}	=	85.72	(ft-lbf/lbm-°R)
R	=	53.34	(ft-lbf/lbm-°R)
μ	=	1.241×10^{-5}	(lbm/ft-s)

gives:

$$Gr = 1.935 \times 10^6\, G\, l^3\, [(0.005\, P\, (T_s - T_\infty) + 1.02\, (P_{T_s} - P_{T\infty})]$$

Substituting for Gr in the mass transfer coefficient equation and letting:

$$
\begin{aligned}
l &= 3.5 \quad (ft) \\
T_s &= T_{ug} \quad (°F) \\
T_\infty &= T_{cab} \qquad (°F) \\
P &= P_{cab} \ (psi)
\end{aligned}
$$

results in:

$$\bar{h}_D = 0.375 \frac{T_{cab} + 460}{P_{cab}} \{P_{cab}\, G\, |(0.005\, P_{cab}\, (T_{ug} - T_{cab})$$

$$+ 1.02\, (P_{Tug} - P_{Tdew})\, |\}^{0.25} \qquad (ft/hr)$$

or for each segment:

$$\bar{h}_{D,j} = \bar{h}_D\, \kappa_2 \ (ft/hr)$$

where $\kappa_2 = \left(\frac{3.5}{l_j}\right)^{1/4}$ and l_j is the segment length defined in Appendix D.1.

Recalling the general form of the equation for maximum evaporative capacity:

$$E_{max} = \bar{h}_{D,j}\, A_C\, V_{effm} \frac{h_{fg}}{R\, T_{gas}} (P_{Tug} - P_{Tdew}) \qquad (Btu/hr)$$

and substituting for $\bar{h}_{D,j}$ and for water vapor properties at 80 °F gives the form of the equation used by the model:

$$E_{max} = 1.32\,\kappa_2\,A_C\,V_{effm}\,\frac{T_{cab} + 460}{P_{cab}}\,\{P_{cab}\,G\,|\,0.005\,Pcab\,(T_{ug} - T_{cab})$$

$$+ 1.02\,(P_{Tug} - P_{Tdew})|\}^{0.25}\,(P_{Tug} - P_{Tdew}) \qquad \text{(Btu/hr)}$$

H.2 SUITED MODE MASS TRANSFER

In the first part of this section the mass transfer coefficient is derived. This coefficient is then used in the derivation of the outlet water vapor pressure of each suit segment.

H.2.1 Mass Transfer Coefficients for Suited Modes

The Nusselt number relation for laminar flow in circular ducts and a combined entry length is [4]:

$$\overline{Nu}_d = \frac{\bar{h}\,d}{k} = 1.86\left(Re\,Pr\,\frac{d}{l}\right)^{1/3}$$

The analogous Sherwood number relation is [2]:

$$\overline{Sh}_d = \frac{\bar{h}_D\,d}{D} = 1.86\left(Re\,Sc\,\frac{d}{l}\right)^{1/3}$$

rearranging gives the mass transfer coefficient equation:

$$\bar{h}_D = 1.86 \frac{D}{d} \left(Re\ Sc \frac{d}{l} \right)^{1/3}$$

or:

$$\bar{h}_D = 1.86 \frac{D}{d} \left(\frac{V\, d\, \rho}{\mu} \frac{\mu}{\rho\, D} \frac{d}{l} \right)^{1/3} = 1.86 \left(\frac{\dot{m}_{gas}\, D^2\, R\, T}{A\, l\, d\;\; 144\, P} \right)^{1/3} \text{ (ft/hr)}$$

Substituting suit dimensions (see Appendix G.2):

$d = 0.222$ (ft)

$l = 3.5$ (ft)

$A = 0.196$ (ft^2)

and:

$D = \frac{12.7}{P} \left(\frac{T}{460} \right)^{1.81}$ (ft^2/hr)

$R = 53.34$ (ft-lbf/lbm-°R)

$T = T_{in}$ (temperature of gas into each segment) (°F)

$P = P_{gas}$ (psi)

yields:

$$\bar{h}_D = 0.00866 \frac{\dot{m}_{gas} (T_{in})^{1.53}}{P_{gas}} \text{ (ft/hr)}$$

and for each segment:

$$\bar{h}_{D,j} = \kappa_3 \, \bar{h}_D \qquad \text{(ft/hr)}$$

where $\kappa_3 = \left(\frac{3.5}{l_j}\right)^{1/3}$.

H.2.2 Derivation of Outlet Water Vapor Pressure Equation

The maximum evaporative capacity for suit segment j is:

$$E_{max} = 1040.0 \, V_{effm} \, \dot{m}_{gas} \left[\frac{18.0 \, (P_{max} - P_{in})}{\mathcal{M}_{gas} \, P_{gas}}\right] \qquad \text{(Btu/hr)}$$

where $\dot{m}_{gas}$ is the mass flow of dry gas P_{max} is the maximum water vapor pressure obtainable through mass transfer from a fully wetted surface. This water vapor pressure limit, dependent on the mass transfer coefficient defined in Appendix H.2.2, is derived below.

Given the inlet water vapor pressure to a suit segment, the outlet water vapor pressure can be determined by considering the mass balance on the skin surface area within that segment. That is, the amount of water vapor diffusing from the skin is equal to the increase of water vapor in the air, assuming the inside suit surface is dry. For an elemental area of skin, dA, this statement translates mathematically into:

$$\frac{\bar{h}_{D,j}}{R_{H_2O} \, T_{gas}} (P_s - P_g) \quad dA \qquad = d\omega \, \dot{m}_{gas}$$

where P_s and P_g are the water vapor pressures of the skin or undergarment and the gas stream, respectively, and $d\omega$ is the differential of the humidity ratio equal to $\frac{\mathcal{M}_{H_2O} \, dP_g}{\mathcal{M}_{gas} \, P_{gas}}$. Let:

$$T_{gas} = (T_{in} + 460.0) \quad (°R)$$

$$\mathcal{M}_{gas} = \frac{1}{R} \quad \text{(lbm-°R/lbf-ft)}$$

substituting for dω and rearranging:

$$\frac{dP_g}{dA} + \left[\frac{144.0\, P_{gas}\, \bar{h}_{D,j}}{R\, \dot{m}_{gas}\, (T_{in} + 460.0)} \right] P_g = \left[\frac{144.0\, P_{gas}\, \bar{h}_{D,j}}{R\, \dot{m}_{gas}\, (T_{in} + 460.0)} \right] P_s$$

Assuming that P_s is constant, this equation is a first order linear differential equation of the form:

$$y' + by = C$$

which can be solved with an integration factor e^{β}, where $\beta = bA$:

$$e^{\beta} y' + be^{\beta} y = Ce^{\beta}$$

$$(e^{\beta} y)' = Ce^{\beta}$$

$$e^{\beta} y = \int^{A} (Ce^{\beta})\ dA$$

$$y = \frac{C}{b} + C_1 e^{-\beta}$$

with the boundary conditions:

1) $A = 0,\ y = P_{in}$

2) $A = A,\ y = P_{out}$

where P_{in} and P_{out} are the water vapor pressures into and out of the suit segment, respectively. Apply condition 1):

$$P_{in} = P_s + C_1$$
$$C_1 = (P_{in} - P_s)$$

Apply condition 2):

$$P_{out}\, e^{\beta} = P_s\, e^{\beta} + (P_{in} - P_s)$$

Thus:

$$P_{out} = P_s + (P_{in} - P_s)e^{-\beta}$$

and substituting for β and let $A = A_C$:

$$P_{out} = P_{in} + (P_s - P_{in})\left[1 - \exp\left(-\frac{144\, P_{gas}\, A_C\, \bar{h}_{D,j}}{\dot{m}_{gas}\, R\, (T_{in} + 460)}\right)\right]$$

where all pressures are in units of psia.

H.3 REFERENCES

1. Eckert, E. R. G. and Drake, R. M. Heat and Mass Transfer," New York: McGraw-Hill Book Company Inc., pp. 311-315 (1959).

2. Jacob, M., Heat Transfer, New York: John Wiley and Sons, Inc. (1955).

3. Lin, S. H. and Berenson, P. J., " Study of the Thermal Processes for Man in Space," AiResearch Manufacturing Co., NASA CR-216 (1965).

4. Sieder, E. N. and Tate, G. E., Industrial Engineering and Chemistry, Vol. 28, p. 1429 (1936).

APPENDIX I

VENTILATION EFFICIENCY

All mass transfer coefficients used in the model for the determination of maximum evaporative capacity are mean values which are based on the assumption of convection with fully-wetted cylindrical body segments. Unless otherwise compensated, errors will result from the use of these mean mass transfer coefficients because the fully-wetted condition only exists on those portions of the surface where sweat production rate is greater than the local mass transfer rate. As is is applied in METMAN, ventilation efficiency, V_{effm}, was developed by Kerslake [1] in order to correct for these errors. What follows is a summary of this work.

I.1 EXPERIMENTAL BASIS FOR VENTILATION EFFICIENCY

Local convection coefficients, h, were measured at 30° intervals around the circumference of a man-sized cylinder (6 ft long, 1 ft diameter) in wind speeds of 2 - 20 ft/s. A plot of h vs. θ produced a consistent pattern for all wind speeds; a plot of $h/\bar{h}$ vs. θ, the ratio of local to mean convection coefficients versus radial position, yielded a single curve with insignificant scatter. This suggests that a single relationship exists, independent of wind speed up to 20 ft/s, for $h/\bar{h}$ vs. θ.

For identical laminar flow conditions, the heat-mass transfer analogy implies that mass transfer coefficients are merely fixed multiples of convection coefficients, i.e. $h_D = nh$ where n is a constant. The relationship of $h_D/\bar{h}_D$ vs. θ should therefore be identical to that of $h/\bar{h}$ vs. θ. The ventilation efficiency is defined as $h_D/\bar{h}_D$ and the $h/\bar{h}$ vs. θ relationship is applied to evaporation of sweat through a mathematical development, beginning with the equation for maximum evaporative capacity:

$$E_{max} = \bar{h}_D \frac{A_C\, h_{fg}}{R\, T_{gas}} (P_{Tug} - P_{Tdew}) \qquad \text{(Btu/hr)}$$

which is based on the mean mass transfer coefficient. The local evaporation is therefore:

$$E = h_D \frac{A_C h_{fg}}{R T_{gas}} (P_{Tug} - P_{Tdew}) \qquad \text{(Btu/hr)}$$

The actual evaporation for a given location can be determined by this equation if the location is fully-wet, that is, $E < q_{swt}$. Dripping of sweat occurs wherever:

$$h_D \frac{A_C h_{fg}}{R T_{gas}} (P_{Tug} - P_{Tdew}) < q_{swt}.$$

Dividing both sides by E_{max} gives:

$$\frac{h_D}{\bar{h}_D} < \frac{q_{swt}}{E_{max}}$$

or:

$$V_{effm} < \frac{q_{swt}}{E_{max}}$$

Thus, wherever $q_{swt}/E_{max} > V_{effm}$, excess sweating occurs. In Figure I.1, ventilation efficiency is plotted against q_{swt}/E_{max}. Actual evaporation is equal to the theoretical maximum predicted by E_{max} only when $q_{swt}/E_{max} \geq 2.0$. The thermoregulatory model reduces maximum evaporative capacity by the V_{effm} factor to compensate for the aforementioned errors. The value of V_{effm} is determined from a lagrangian interpolation of the data points in this figure (see Section 4.1.3, Curve Data) [2].

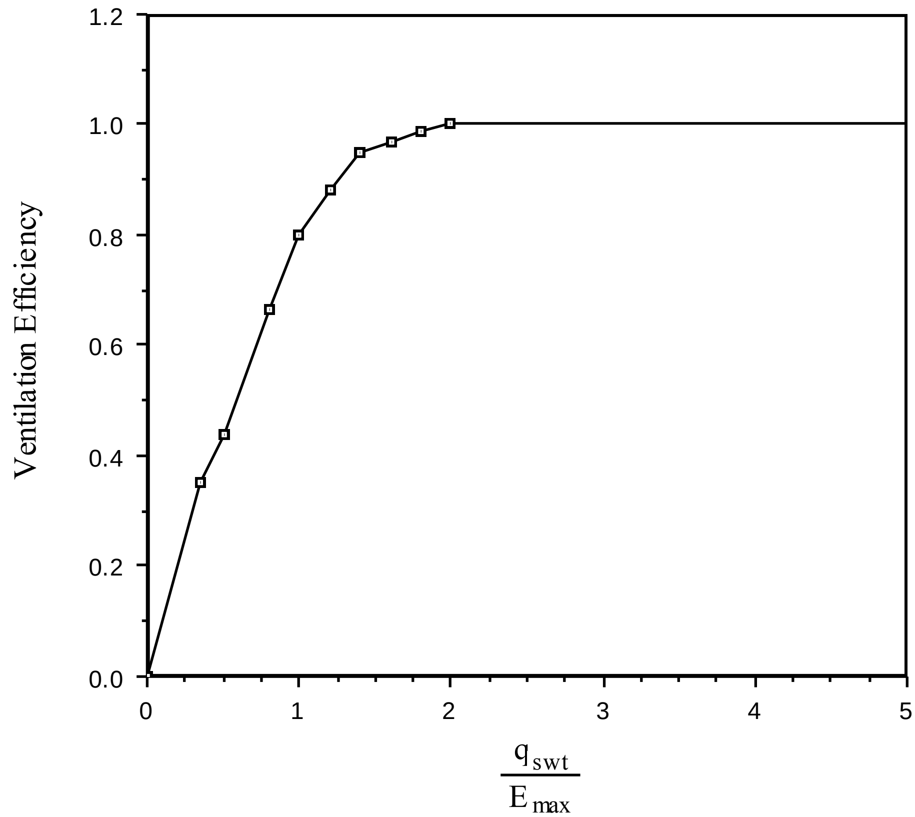

Figure I.1 Ventilation Efficiency vs. q_{swt}/E_{max}

Note that the experimental model assumes a uniform sweat rate and a stationary man. Since neither of these assumptions are true, the use of V_{effm} tends to overestimate sweat evaporation.

I.2 REFERENCES

1. Kerslake, D. M. "Errors Arising from the Use of Mean Heat Exchange Coefficients in the Calculation of the Heat Exchanges of a Cylindrical Body in a Transverse Wind." Temperature, Vol. 3 , Biology and Medicine, J. D. Hardy (Ed.), New York: Reinhold (1963), pp. 183-190.

2. Nguyen, N. H., "Updated Shuttle EMU Comfort Curves," Transmittal, Lockheed Electronics Company, AMD/173, (December 1978).

APPENDIX J
PROGRAM LISTINGS

The FORTRAN Source Code of the main program, subroutines and functions of METMAN are presented in this section in the same order as section 5.

J.1 MAIN PROGRAM

```
       PROGRAM MAIN
C
C***************************************************************************
C***************************************************************************
C*****                                                                 *****
C*****                  TRANSIENT METABOLIC MAN PROGRAM                *****
C*****                    ( 41 NODE METABOLIC MAN )                    *****
C*****                                                                 *****
C*****                         MSC PROGRAM J196                        *****
C*****                                                                 *****
C*****                         PROJECT   3703-I                        *****
C*****                                                                 *****
C*****                                                                 *****
C*****                           WRITTEN BY                            *****
C*****                                                                 *****
C*****                         LOIS W MORGAN                           *****
C*****                                                                 *****
C*****                            D W COOK                             *****
C*****                                                                 *****
C*****                        GEORGE F COLLETT                         *****
C*****                                                                 *****
C*****                                                                 *****
C*****                  LOCKHEED ELECTRONICS COMPANY                   *****
C*****         HOUSTON AEROSPACE SYSTEMS DIVISION,  HOUSTON, TEXAS     *****
C*****                                                                 *****
C*****                            MAY 1970                             *****
C*****                                                                 *****
C*****                                                                 *****
C***************************************************************************
C***************************************************************************
C*****                                                                 *****
C*****            CONVERTED TO FORTRAN-77 (11-83) BY G. BROWN          *****
C*****                                                                 *****
C*****      MODIFIED & ENHANCED BY J. IOVINE (1987-) & G. BUE (1989-)  *****
C*****                                                                 *****
C***************************************************************************
C
      PARAMETER (MM=71,M2=MM+2)
      PARAMETER (NCRV=18,NCR=NCRV-1+10)
      LOGICAL CURVES,CTGIN,CTDEW,CTWI,CPCAB,CPGC,CPO2,CRM,CUEFF,CWF,
     $        CCFMS,IMPAIR,INIT,IPURGE,LCG,EVA,ITHERM,CAKS,DAKS,CQASRB,
     $        IPLOP,STEPF,CTDEWC,CTCAB,CVCAB,CTW,CMODE,IPLOPO,TERM,TSAV,
     $        CRVL,AVRM
      LOGICAL DONT,ENDONX,OKPC,HELP,TRAN
```

```
      INTEGER  OPAKS
      INTEGER  POSTN
      REAL LONG,LAT
      DOUBLE PRECISION QVECTS
C
      DIMENSION TIS(10), TOS(10), BF(40), QUGIS(10), QISG(10),
     $          ACSUTE(10), QOSW(10), QOSA(10), SUITA(10), QUGG(10)
      DIMENSION CCTGIN(50),CCTDEW(50),CCRM(50),CCPCAB(50),CCPO2(50),
     $          CCPGC(50),CCCFMS(50),CCTWI(50),CCWF(50),CCUEFF(50),
     $          SAVT(43),SAVTOS(10),SAVTIS(10),SAVTUG(10),STGOUT(10),
     $          SAVTG(10),SAVTM(10),CCAKS(50),DDAKS(50),CCQASB(50,10),
     $          PH2OO(10),PH2OI(10),CCTDWC(50),CCTCAB(50),CCVCAB(50),
     $          CCTW(50),CCMODE(50)
C
      EQUIVALENCE (TSKIN,T(72)),(TCORE,T(1))
      EQUIVALENCE (T(42),TIS(1)),(T(52),TOS(1))
      EQUIVALENCE (T(62),THX),(T(63),TDUCT),(T(64),TDUCT2),
     $ (T(65),TPIPE),(T(66),TPIPE2)
      EQUIVALENCE ( CRVL(1),CQASRB),( CRVL(2),CMODE),( CRVL(3),CTGIN),
     $        ( CRVL( 4),CTDEW ),( CRVL( 5),CTWI  ),( CRVL( 6),CPCAB ),
     $        ( CRVL( 7),CPGC  ),( CRVL( 8),CPO2  ),(CRVL( 9),CRM   ),
     $        ( CRVL(10),CUEFF ),( CRVL(11),CWF   ),( CRVL(12),CCFMS ),
     $        ( CRVL(13),CAKS  ),( CRVL(14),DAKS  ),( CRVL(15),CTDEWC),
     $        ( CRVL(16),CTCAB ),( CRVL(17),CVCAB ),( CRVL(18),CTW   )
      EQUIVALENCE (ICRVP(1),NPQASB),(ICRVP(2),NPMODE),(ICRVP(3),NPTGIN),
     $        (ICRVP( 4),NPTDEW),(ICRVP( 5),NPTWI ),(ICRVP( 6),NPPCAB),
     $            (ICRVP( 7),NPPGC ),(ICRVP( 8),NPPO2 ),(ICRVP( 9),NPRM  ),
     $            (ICRVP(10),NPUEFF),(ICRVP(11),NPWF  ),(ICRVP(12),NPCFMS),
     $        (ICRVP(13),NPAKS ),(ICRVP(14),OPAKS ),(ICRVP(15),NPTDWC),
     $        (ICRVP(16),NPTCAB),(ICRVP(17),NPVCAB),(ICRVP(18),NPTW  )
      EQUIVALENCE (CRVS(1,1),CCQASB(1,1)),(CRVS(1,11),CCMODE),
     $            (CRVS(1,12),CCTGIN),    (CRVS(1,13),CCTDEW),
     $            (CRVS(1,14),CCTWI ),    (CRVS(1,15),CCPCAB),
     $            (CRVS(1,16),CCPGC ),    (CRVS(1,17),CCPO2 ),
     $            (CRVS(1,18),CCRM  ),    (CRVS(1,19),CCUEFF),
     $            (CRVS(1,20),CCWF  ),    (CRVS(1,21),CCCFMS),
     $            (CRVS(1,22),CCAKS ),    (CRVS(1,23),DDAKS ),
     $            (CRVS(1,24),CCTDWC),    (CRVS(1,25),CCTCAB),
     $            (CRVS(1,26),CCVCAB),    (CRVS(1,27),CCTW  )
      EQUIVALENCE (T(5),T5),(T(4),T4),(T(8),T8),(T(12),T12),(T(20),T20)
      EQUIVALENCE (T(28),T28),(QCOND(7),QCOND7),(QMET(8),QMET8),
     $            (QLAT(8),QLAT8),(QCONV(8),QCONV8),(QSEN(8),QSEN8),
     $            (QRAD(8),QRAD8),(QLCG(8),QLCG8),(QCOND(19),QCOND19),
     $            (QMET(20),QMET20),(QLAT(20),QLAT20),
     &            (QCONV(20),QCONV20),(QSEN(20),QSEN20),
     &            (QRAD(20),QRAD20)
C
      COMMON/METCOM/ MODE,ICOND,INIT,IPURGE,II(10),CURVES,RM,UEFF,AC,AR,
     &       TCAB,TW,VCAB,PCAB,ALUG,AKUG,EUG,WF,TWI,CPW,UAG,
     &       DTIME,TDEWC,TDEW,U,ACSUIT(10),ARSUIT(10),CPG,CFMS,
     &       TGIN,PG,PO2,ALS(10),AKS(10),EIS(10),EOS(10),CPS(10),
     &       QASRB(10),VF,VEFF,WORK,TUGAV,WS(10),C(41),TWO,SQUG,
     &       QEVAP,TOTL,QSHIV,QSTOR,STORAT,SCAB1,CLO,TISAV,WG,
     &       TOSAV,TGOUTS,RMIX,PN2,QLCG(40),QSEN(40),QRAD(40),
     &       TSET(43),EMAX(40),PCFLO(5),G,TUG(10),TGOUT(10),TG(10),
     &       TM(10),WH2OO,WO2OUT,WCO2O,WGOUT,SHSO,PULSE,QR,IPLOP,
     &       TDEWA,SCABC,QRSEN1,QRSEN5,ACE(10),SQUGW,QLAT(40),
     &       WGIN,VOLHMT,HCO2MH,QRSEN2,QRSEN3,QRSEN6,WH2OIN,QRSE15,QD
```

```
      COMMON/TMAT/QVECTS(MM),QVECT(MM),TDIFF,QVECST,
     $       PREC,DONT,HELP,OLDT,H,ENDONX,XHAT,OKPC,TRAN,WGE10,
     $       NCO2,T(M2),NMT,IQ,ICYCLE,IFLG,NB(MM),MINUT,INITL

c      COMMON/TMAT/QVECT(MM),NMT,IQ,QVECTS(MM),ICYCLE,TDIFF,IFLG,QVECST,
c     $           NB(MM),MIN,PREC,DONT,INITL,HELP,OLDT,H,ENDONX,XHAT,OKPC,
c     $       TRAN,WGE10,NCO2,T(M2)
      COMMON/LCG/ WDOT1,UASB,EL,EL2,DE,WT,CPHX,WTDUCT,CPDUCT,WTDUC2,
     $       ELP,ELP2,DEP,RHOC,WTPIPE,WTPIP2,CPP,SUBKA,UAHXS,WN2
      COMMON/PRESS/PH2OO,PH2OI,PH2OOO(10)
      COMMON/DWC/TIME
      COMMON/DIAG/PTIM
      COMMON/QTSUIT/QTSUIT
      COMMON/XHATCK/CRVL(NCRV),ICRVP(NCRV),CRVS(50,NCR),XHATAR(50),JT
      COMMON/SOL/ARTOT1,AVRTOT,SQABS,ITIME
      COMMON/HUM/WTMXD
      COMMON/GFC/SUBIN,SUBOUT,PH2OSO,MODEO
      COMMON/CHGTGI/TAVD,TAVD2,TAVP,TAVP2
      COMMON/FEEDWA/FDWTRR
      COMMON/HUDUNT/QMET(40),QCOND(40),QCONV(40)
      COMMON/GO/UAHX
      COMMON/POSTL/ RGAS,PA,CFMC,DENSA,NUMEN,AREAW,VOLCAB,RHOCOA,TATM,
     $             CO2MMH,IQV,CPA,QCNDEN,TOTCON
      COMMON/TEST/STEPF
      COMMON /BLUD/TBF,TSBF,BF,SROR,EMTOT
      COMMON/SKIN/TAVSKN,O2RATE,CO2RAT
      COMMON/UAGNEW/CCUAG(26),NPUAG
      COMMON/DERSUT/ QUGIS,QISG,ACSUTE,QOSW,QOSA,SUITA,SQOSA,SQOSW,
     $              QUGG
      COMMON/NOMO/HEIGHT,WEIGHT,AVRM
      COMMON/BSIZE/BRM
C
      NAMELIST /TEST/ T4,T5,T8,T12,T20,SQUGW,SQOSA,SQOSW,SROR,
     $         TDEWOT,EMTOT,TAVSKN,UAG,QRSE15,SCONV,SLCG,QR,QD
      NAMELIST /TSUIT/ TIS,TOS
      NAMELIST /INPUT/ MODE,RM,UEFF,AC,ARI,TCAB,TW,TDEWC,VCAB,VEFF,PCAB,
     $        G,ALUG,AKUG,EUG,ACSUIT,ARSUIT,ALS,AKS,EOS,EIS,WS,CPS,
     $        QASRB,VF,VOLHMT,CFMS,TGIN,TDEW,CPG,PG,PO2,IPURGE,LCG,
     $        ITHERM,UASB,WF,TWI,CPW,UAG,DT,PRINTI,SETI,MCASES,IPLOP,
     $        RA,TATM,VOLCAB,PO2A,PN2A,CPA,NUMEN,PA,AREAW,TDEWA,
     $        CFMC,CURVES,CTGIN,NPTGIN,CCTGIN,CTDEW,NPTDEW,CCTDEW,CRM,
     $        NPRM,CCRM,CPCAB,NPPCAB,CCPCAB,CPO2,NPPO2,CCPO2,CPGC,NPPGC,
     $        CCPGC,CCFMS,NPCFMS,CCCFMS,CTWI,NPTWI,CCTWI,CWF,NPWF,CCWF,
     $        CUEFF,NPUEFF,CCUEFF,CAKS,NPAKS,CCAKS,DAKS,OPAKS,DDAKS,
     $        CQASRB,NPQASB,CCQASB,RQ,UAHX,EL,EL2,DE,WT,CPHX,WTDUCT,
     $        CPDUCT,WTDUC2,ELP,ELP2,DEP,RHOC,WTPIPE,WTPIP2,CPP,SUBKA,
     $        UAHXS,DONT,TDIFF,CTDEWC,CCTDWC,NPTDWC,CTCAB,
     $        CCTCAB,NPTCAB,CVCAB,CCVCAB,NPVCAB,CTW,CCTW,NPTW,STEPF,
     $        CMODE,CCMODE,NPMODE,TSAV,TWALPL,TZ,LONG,LAT,CN,ROG,CCM,
     $        IDAY,ITIME,SQABS,WTRTO,G1,G2,G3,G4,DTLCG,TWO,HEIGHT,
     $        WEIGHT,AVRM
C
      NAMELIST /OUT/ T,QVECT,QVECTS,QVECTT,IQ,ICYCLE,ICNTR,QVECST
      NAMELIST /SOLAR/ ARTOT1,AVRTOT
      NAMELIST /RUN/ TBF,TMBF,TSBF,PULSE,T5,WTLSS,SENSIN,TOTLIN,
     $            T8,T28,T20,T4,QCOND7,QMET8,QLAT8,QCONV8,QSEN8,QRAD8,
     $            QLCG8,QCOND19,QMET20,QLAT20,QCONV20,QSEN20,QRAD20
      SAVE
```

```
C
C
C  IF ANY CURVE DIMENSION IS CHANGED CRVS MUST BE REDIMENSIONED
C  IF NEW CURVES ARE ADDED NCRV,ICRVP,CRVS, AND CRVL SHOULDBE UPDATED
C
C  DEFINITION OF BODY SEGMENT TEMPERATURE SUBSCRIPTS
C  T(1)  = HEAD CORE         T(2)  = HEAD MUSCLE      T(3)  = HEAD FAT
C  T(4)  = HEAD SKIN         T(5)  = TRUNK CORE       T(6)  = TRUNK MUSCLE
C  T(7)  = TRUNK FAT         T(8)  = TRUNK SKIN       T(9)  = RIGHT ARM CORE
C  T(10) = RIGHT ARM MUSCLE  T(11) = RIGHT ARM FAT    T(12) = RIGHT ARM SKIN
C  T(13) = LEFT ARM CORE     T(14) = LEFT ARM MUSCLE  T(15) = LEFT ARM FAT
C  T(16) = LEFT ARM SKIN     T(17) = RIGHT LEG CORE   T(18) = RIGHT LEG MUSCLE
C  T(19) = RIGHT LEG FAT     T(20) = RIGHT LEG SKIN   T(21) = LEFT LEG CORE
C  T(22) = LEFT LEG MUSCLE   T(23) = LEFT LEG FAT     T(24) = LEFT LEG SKIN
C  T(25) = RIGHT HAND CORE   T(26) = RIGHT HAND MUSCLET(27) = RIGHT HAND FAT
C  T(28) = RIGHT HAND SKIN   T(29) = LEFT HAND CORE   T(30) = LEFT HAND MUSCLE
C  T(31) = LEFT HAND FAT     T(32) = LEFT HAND SKIN   T(33) = RIGHT FOOT CORE
C  T(34) = RIGHT FOOT MUSCLE T(35) = RIGHT FOOT FAT   T(36) = RIGHT FOOT SKIN
C  T(37) = LEFT FOOT CORE    T(38) = LEFT FOOT MUSCLE T(39) = LEFT FOOT FAT
C  T(40) = LEFT FOOT SKIN    T(41) = CENTRAL BLOOD    T(72) = AVERAGE SKIN
C  T(73) = AVERAGE MUSCLE
C
C  T'S USED FOR SUITED MODE
C T(42-51) = INSIDE THE SUIT        T(52-61) = OUTSIDE THE SUIT
C T(62)    = TEMP. SUBLIMATOR       T(63)    = TEMP. DUCT BTWN SUBL,PRES SUIT
C T(64)=TEMP DUCT BTWN SUIT, SUBL   T(65)    = TEMP. PIPE BTWN LCG,SUBL
C T(66)=TEMP PIPE BTWN SUBL AND LCG T(67)    = TOTAL CO2 IN HELMET
C
C T'S USED FOR POSTLANDING OPTION IN SHIRTSLEEVES MODE
C T(42)=TOT. WT. WATER VAPOR,LB     T(43)=CO2 CONCEN. IN CABIN ATMOSPHERE
C T(44)=CABIN TEMP.                 T(45)=WALL TEMP.
C
C  T'S USED FOR POSTLANDING OPTION IN SUITED MODE
C T(62)=TOT. WT. WATER VAPOR,LB     T(63)=CO2 CONCEN. IN CABIN ATMOSPHERE
C T(64)=CABIN TEMP.                 T(65)=WALL TEMP.
C
C
C  INPUT TIME IN MINUTES
C  MODE=0 SHIRTSLEEVES MODE
C  MODE=1 NORMAL SUITED MODE
C  MODE=2 EVA SUITED MODE
C  MODE =3 HELMET-OFF SUITED MODE
C
C
      DATA CCUAG/ 50.0,10.0, 100.0,28.5, 150.0,37.5, 200.0,42.5,
     $           250.0,45.5, 300.0,47.5, 350.0,49.5, 700.0,65.0,
     $           750.0,67.0, 800.0,68.5, 850.0,69.5, 900.0,70.0,
     $           2000.0,70.0/
      DATA NPUAG/13/
      DATA(TSET(I),I=1,41)/98.6,97.6,97.0,96.6,98.8,98.3,95.9,94.4,96.1,
     $                     95.1,94.1,93.7,96.1,95.1,94.1,93.7,97.6,96.5,
     $                     95.1,94.5,97.6,96.5,95.1,94.5,95.9,95.7,95.6,
     $                     95.5,95.9,95.7,95.6,95.5,95.8,95.5,95.7,95.5,
     $                     95.8,95.5,95.7,95.5,98.5/
      DATA( PCFLO(J),J=1,5)/.2,.125,.125,.275,.275/
      DATA NB/71*0/,ARI/15.5/
      DATA NCO2 / 67 /
C  RQ UPDATED FROM 0.82 TO 0.9 BY JVI, 11-8-89
```

```
      DATA RQ, PCAB, VCAB, CPG /0.9, 14.7, 0., 0.24/
      DATA TZ,LONG,LAT,CN,ROG,CCM/6.0,89.0,30.0,1.0,0.2,1.0/
      DATA SQABS/0.6/
      DATA VEFF/100.0/
      DATA HEIGHT, WEIGHT, AVRM / 67., 154., .FALSE. /
C
C UNIX 8/00 OUTPUT FILE, JVI
C
      OPEN ( 2, FORM = 'FORMATTED', STATUS = 'UNKNOWN',
     $          FILE = 'case.out' )
      OPEN ( 1, FORM = 'FORMATTED', STATUS = 'OLD',
     $          FILE = 'case.inp' )
C
      TOTCON=0.0
      PA = 0.0
      PO2 = 0.0
      PN2 = 0.0
      RA = 0.0
      CPA =0.0
    1 ICOND=0
      IMPAIR = .FALSE.
      KOUNT=0
      KOUNTR = 0
    2 READ(1,INPUT,END=103)
C   2 READ(5,INPUT,END=103)
C
      CALL BODYSZ(MODE,C,RM,AC,AR,ACSUIT,ARSUIT,WS)
C
      IF(TDEWC.GT.TCAB)TDEWC=TCAB
      IF(TDEW.GT.TGIN)TDEW=TGIN
      WRITE(2,1002)
C     WRITE(2,INPUT)
      TRAN=.TRUE.
      WRITE(2,1003)
C
      TAVD=75.
      TAVD2=75.
      TAVP=75.
      TAVP2=75.
      SUBOUT=75.
      DO 500 I=62,66
  500 T(I)=75.
      XO2RAX=0.
      XCO2RX=0.
      XTOTLX=0.
      XFDWTX=0.
      IF(CPA .LE. 0.0) CPA=0.24
      RGAS = 53.3
      IF (RA.NE.0.0)RGAS=RA
      IF(PA .LE. 0.0) PA=14.7
      IF (PO2A.NE.0.0.AND.PN2A.NE.0.0)RGAS=
     $            1545./(PO2A/PA*32.+PN2A/PA*28.)
      DENSA = PA/(RGAS*(TATM+460.))*144.
      RHOCOA = .00406*144.*44./(1545.*(TATM+460.))
      IF(ICOND.EQ.0)RHOCO2 = .00406*144.*44./(1545.*(TCAB+460.))
      IF(ICOND.EQ.0)CO2MMH = 0.00406*760./14.7
C
    3 CONTINUE
```

```
C
      TERM=.FALSE.
      IF(ICOND .LT. 2) TIME=0
      IF(.NOT. CURVES .OR. .NOT. IPLOP) GO TO 4
      CURVES=.FALSE.
      WRITE(2,1023)
    4 CONTINUE
      QVECST=25000000.0
C     CALL RESET
      TOTCON=0.0
      QCNDEN=0.
C
C  INPUT FOR CRANE
      JT=0
      IF( .NOT. CURVES)GO TO 5
C
C  SUBROUTINE DISCON STORES THE TIME POINTS OF THE CURVE STEP CHANGES
C  SO THAT CRANE CAN STEP MORE ACCURATELY
      CALL DISCON
    5 CONTINUE
      ENDONX=.TRUE.
      JT=JT+1
      XHATAR(JT)=SETI/60.
      IF(JT .EQ. 1)GO TO 6
C
C  PUT THE XHAT VALUES IN ASCENDING ORDER
      CALL ASCEND(XHATAR,JT)
    6 CONTINUE
      XHAT=XHATAR(1)
      IXH=1
      PREC=5.0
      IF(ICOND .EQ. 0) PREC=3.
      OLDT=-1.
      DTIME=DT/60.
      MINUT=3
      VPPCAB = VPP(TDEWC)
      IF (PCAB .GT. 0.) THEN
         SPHCAB=VPPCAB*18/(PCAB*29.)
      ELSE
         SPHCAB = 0.
      ENDIF
      TOTCO2=0.0
      TOTO2=0.0
      TOTWCN=0.0
      FDWTR=0.0
    7 CONTINUE
      H=DTIME
      INITL=0
      PT = H
      AR=ARI
      IF(MODE .GT. 0) AR=AC
      IF(MODE-1)8,10,11
    8 WRITE(2,1019)
      IF(ITIME.LE.0.0)GO TO 9
      CALL SUN(TZ,LONG,LAT,0.0,CN,ROG,CCM,IDAY,ITIME,0,0,ARTOT1)
      CALL SUN(TZ,LONG,LAT,90.0,CN,ROG,CCM,IDAY,ITIME,-179,180,AVRTOT)
    9 CONTINUE
C     WRITE(2,SOLAR)
```

```
      GO TO 13
   10 WRITE(2,1020)
      GO TO 13
   11 IF (MODE .GT. 2) GO TO 12
      EVA = .TRUE.
      WRITE(2,1021)
      GO TO 13
   12 WRITE(2,1022)
   13 IF (IPLOP) WRITE(2,1038)
      IF(.NOT. IPLOP) GO TO 14
      WRITE(2,1040)RGAS,TATM,VOLCAB,PO2A,PN2A,CPA,NUMEN,PA,AREAW,
     $             TDEWA,CFMC
   14 CONTINUE
      IF (AVRM)THEN
           WRITE(2,1043)RM,UEFF,AC,AR,HEIGHT,WEIGHT
      ELSE
           WRITE(2,1004)RM,UEFF,AC,AR,HEIGHT,WEIGHT
      END IF
C
      INIT=.TRUE.
      WRITE(2,1005)
      IF (.NOT. EVA) WRITE(2,1006)VF
      WRITE(2,1008)TCAB,TW,VCAB,PCAB
      IF (.NOT. EVA) WRITE(2,1009)TDEWC,G
      WRITE(2,1010)ALUG,AKUG,EUG
      IF (LCG) WRITE(2,1011)WF,TWI,CPW,UAG
C
C
      IF ( MODE .EQ. 0) GO TO 15
      WRITE(2,1012)
      IF (EVA) WRITE(2,1007)QASRB
      WRITE(2,1014)CFMS,CPG,TGIN,TDEW,PG,PO2,ARSUIT(1),ARSUIT(2),ARSUIT
     $            (4),ARSUIT(10),ARSUIT(6),ARSUIT(8)
      WRITE(2,1032)ACSUIT(1),ACSUIT(2),ACSUIT(4),ACSUIT(10),ACSUIT(6),
     $            ACSUIT(8),WS(1),WS(2),WS(4),WS(10),WS(6),WS(8)
      WRITE(2,1033)CPS(1),CPS(2),CPS(4),CPS(10),CPS(6),CPS(8),ALS(1),ALS
     $            (2),ALS(4),ALS(10),ALS(6),ALS(8)
      WRITE(2,1034)AKS(1),AKS(2),AKS(4),AKS(10),AKS(6),AKS(8),EIS(1),EIS
     $            (2),EIS(4),EIS(10),EIS(6),EIS(8)
      WRITE(2,1035)EOS(1),EOS(2),EOS(4),EOS(10),EOS(6),EOS(8)
      IF (IPURGE)       WRITE(2,1013)
      WRITE(2,1041) SETI
C
C  INITIALIZE
C
   15 CLO=ALUG/AKUG
      SETT=SETI/60.
      PRINT=PRINTI/60.
C
C  SUITED OR SHIRTSLEEVES FOR INITIAL CONDITIONS ONLY
C
      IF(ICOND .NE. 0) GO TO 16
      IFLG=0
      IQ=0
      ICYCLE=0
      ICNTR=0
      SQUG=0.
      QEVAP=0.
```

```
      TOTL=0.
      QSHIV=0.
      QSTOR=0.
      STORAT=0.
      SCAB1=0.
      TUGAV=TSKIN
      TGOUTS=0.
      TISAV=0.
      TOSAV=0.
      DO 502 I=1,41
  502 T(I)=TSET(I)
   16 IF ( MODE .EQ. 0 ) GO TO 69
C
C   SUITED HEADING
C
      WRITE(2,1015)
      KOUNTR = 6
      PRNOW=TIME
      PTIM=TIME*60.
      IF(ICOND .GT. 1 .AND. MODEO .NE. 0) GO TO 17
      POSTN = 2
      DELAY = 0.0
   17 CONTINUE
      WDOT1=WF*0.125
      NMT=61
      IF(UASB .GT. 0) NMT=66
      IF(.NOT. IPLOP) GO TO 18
      NMT=65
      IQV=62
      IF(ICOND .NE. 0 .AND. IPLOPO) GO TO 18
      T(IQV)=VOLCAB*PCAB/(RGAS*(TCAB+460.))*SPHCAB*144.
      T(64)=TCAB
      T(65)=TW
C
C  INITIAL VALUES FOR WEIGHT OF WATER VAPOR IN CABIN AND CO2 IN CABIN
C  DURING POSTLANDING
C
      T(IQV+1)=VOLCAB*RHOCO2
   18 CONTINUE
      IF(UASB .EQ. 0 .OR. .NOT. IPLOP) GO TO 19
      UASB=0
      WRITE(2,1024)
      KOUNTR = KOUNTR + 1
   19 CONTINUE
C
C  MAIN LOOP FOR SUITED CASE
C
      WRITE(2,1016) PTIM,TGOUTS,SHSO,T(1),T(72),TISAV,TOSAV,QTSUIT,SQUG,
     $                QEVAP,TOTL,STORAT,QSHIV,QSTOR
      KOUNTR = KOUNTR + 1
      DELTAT = TWO - TWI
      SUBDT = SUBOUT - SUBIN
      IF(LCG) THEN
           WRITE(2,1036)TWI,TWO,DELTAT,TDEW,TGIN,TOTO2,TOTCO2,TOTWCN,
     $                  FDWTR,RM,WF
          KOUNTR = KOUNTR + 11
      END IF
      OTPR=760.0/14.7*PH2OSO
```

```
      TDEWOT=DEWPT(OTPR)
      OTPRI=PG*SHSO*32.0/18.0*760.0/14.7
      TDWOT1=DEWPT(OTPRI)
      SATPRS=VPP(TGOUTS)
      RELHUM=PH2OSO/SATPRS
      IF (MODE .EQ. 1 .OR. MODE .EQ. 2) THEN
          WRITE(2,1042)HCO2MH
          KOUNTR = KOUNTR + 2
      END IF
      KOUNTR = KOUNTR + 13
      PRNOW=PRNOW+PRINT
   20 OLDSTR = STORAT
      IF (.NOT. CURVES)GO TO 24
      IF(ICOND .EQ. 0 .OR. .NOT. CMODE) GO TO 21
      CALL LAGIN(14,CCMODE,NPMODE,2,TIME,RMODE)
      MODEC=RMODE+.001
      IF(MODEC .EQ. MODE) GO TO 21
      KOUNTR=0
      WRITE(2,1002)
      MODEO=MODE
      MODE=MODEC
      EVA=.FALSE.
      GO TO 7
   21 CONTINUE
      IF(CTCAB)CALL LAGIN(7,CCTCAB,NPTCAB,2,TIME,TCAB)
      IF(CTW)CALL LAGIN(7,CCTW,NPTW,2,TIME,TW)
      IF (CTGIN) CALL LAGIN (1,CCTGIN,NPTGIN,2,TIME,TGIN)
      IF (CTDEW) CALL LAGIN (2,CCTDEW,NPTDEW,2,TIME,TDEW)
      IF (CTWI ) CALL LAGIN (3,CCTWI,NPTWI,2,TIME,TWI)
      IF (CPCAB) CALL LAGIN (4,CCPCAB,NPPCAB,2,TIME,PCAB)
      IF (CPGC ) CALL LAGIN (5,CCPGC,NPPGC,2,TIME,PG)
      IF (CPO2 ) CALL LAGIN (6,CCPO2,NPPO2,2,TIME,PO2)
      IF (CRM  ) CALL LAGIN (7,CCRM,NPRM,2,TIME,RM)
      IF (CUEFF) CALL LAGIN (8,CCUEFF,NPUEFF,2,TIME,UEFF)
      IF(.NOT. CWF) GO TO 22
      WFOLD=WF
      CALL LAGIN(9,CCWF,NPWF,2,TIME,WF)
      WDOT1=WDOT1*WF/WFOLD
   22 CONTINUE
      IF (CCFMS) CALL LAGIN (10,CCCFMS,NPCFMS,2,TIME,CFMS)
      IF (.NOT. CAKS) GO TO 23
      CALL LAGIN (11,CCAKS,NPAKS,2,TIME,AKST)
      DO 503 I=1,10
      AKS(I)=AKST
  503 CONTINUE
      IF(DAKS)CALL LAGIN(12,DDAKS,OPAKS,2,TIME,AKS(10))
   23 IF (.NOT. CQASRB) GO TO 24
      DO 504 I=1,10
      CALL LAGIN(13,CCQASB(1,I),NPQASB,2,TIME,QASRB(I))
  504 CONTINUE
   24 CONTINUE
      IF(TRAN .OR. IQ.EQ. 0) GO TO 25
      CALL TMATRX
   25 CONTINUE
C
C
      CALL SUIT
C
```

```
C
      PT = H
C
C     IF(PTIM .LT. 5.0) THEN
C         KOUNTR = KOUNTR + 13
C     END IF
C
      O2RATE= (0.0001708-((RQ-0.707)/0.273*0.0000123))*RM
      CO2RAT=O2RATE*44.0/32.0*RQ
      TOTLAT=(TOTL+CO2RAT*425.0)/1040.0
      TOTO2=(O2RATE+XO2RAX)/2.*H+TOTO2
      TOTCO2=(CO2RAT+XCO2RX)/2.*H+TOTCO2
      TOTWCN=TOTWCN+(TOTLAT+XTOTLX)/2.*H
      FDWTR=FDWTR+H*(FDWTRR+XFDWTX)/2.
      XO2RAX=O2RATE
      XCO2RX=CO2RAT
      XTOTLX=TOTLAT
      XFDWTX=FDWTRR
      IF (.NOT. ITHERM) GO TO 35
      IF(UASB.GT.0.0)GO TO 26
      IF(QSTOR.GT.50.0)TWI=TWI-1.0
      IF(TWI.LE.45.0)TWI=45.0
      IF(QSHIV.GT.50.0)TWI=TWI+1.0
      IF(TWI.GE.90.0)TWI=90.0
      GO TO 35
   26 CONTINUE
      QSTRMX = ((RM - BRM) / 13.2) + 65.
      QSTRMN = ((RM - BRM) / 13.2) - 65.
      IF (QSTOR .GT. QSTRMX ) GO TO 27
      IF (QSTOR .LT. QSTRMN ) GO TO 28
      IF(QSHIV.GT.0.0)GO TO 28
      GO TO 34
   27 IF (DELAY .GT. TIME) GO TO 34
      IF (POSTN .EQ. 3 ) GO TO 34
      POSTN = POSTN + 1
      GO TO 29
   28 IF (DELAY .GT. TIME) GO TO 34
      IF (POSTN .EQ. 1) GO TO 34
      POSTN = POSTN - 1
   29 IF (POSTN - 2) 30,31,32
   30 WDOT1 = 0.0375 * WF
      GO TO 33
   31 WDOT1 = 0.125 * WF
      GO TO 33
   32 WDOT1 = 0.99 * WF
   33 DELAY = TIME + .05
   34 CONTINUE
   35 CONTINUE
      IF(TRAN) GO TO 36
      IF(IQ .EQ. 0 .OR. IQ .EQ. -1) GO TO 38
      GO TO 20
   36 CONTINUE
      IF (PRNOW .GT. TIME) GO TO 50
      PRNOW=PRNOW+PRINT
   37 PTIM=TIME*60.
   38 CONTINUE
      IF (.NOT. IMPAIR .AND. QSTOR .GT. 300) GO TO 39
      GO TO 42
```

```
39 IMPAIR = .TRUE.
   IF (KOUNTR .GT. 24) GO TO 40
   WRITE(2,1028)
   WRITE(2,1029)
   GO TO 41
40 WRITE(2,1015)
   KOUNTR = 6
   WRITE(2,1029)
41 WRITE(2,1030)
   KOUNTR = KOUNTR+24
42 IF (IMPAIR .AND. QSTOR .GT. 1000) GO TO 43
   GO TO 46
43 IF (KOUNTR .GT. 24) GO TO 44
   WRITE(2,1028)
   WRITE(2,1029)
   GO TO 45
44 WRITE(2,1015)
   KOUNTR = 6
   WRITE(2,1029)
45 WRITE(2,1031)
   KOUNTR = KOUNTR +24
   TERM=.TRUE.
   GO TO 58
46 CONTINUE
   IF (LCG .AND. KOUNTR .GT. 32) THEN
       WRITE(2,1015)
       KOUNTR = 6
   ELSEIF (KOUNTR .GT. 86) THEN
       WRITE(2,1015)
       KOUNTR = 6
   END IF
   WRITE(2,1016) PTIM,TGOUTS,SHSO,T(1),T(72),TISAV,TOSAV,QTSUIT,SQUG,
  $                QEVAP,TOTL,STORAT,QSHIV,QSTOR
   KOUNTR = KOUNTR + 1
   DELTAT = TWO - TWI
   SUBDT = SUBOUT - SUBIN
   OTPR=760.0/14.7*PH2OSO
   TDEWOT=DEWPT(OTPR)
   OTPRI=PG/(18.0/(WTMXD*SHSO)+1.0)*760.0/14.7
   TDWOT1=DEWPT(OTPRI)
   SATPRS=VPP(TGOUTS)
   RELHUM=PH2OSO/SATPRS
   IF(LCG) THEN
        WRITE(2,1036)TWI,TWO,DELTAT,TDEW,TGIN,TOTO2,TOTCO2,TOTWCN,
  $                     FDWTR,RM,WF
       KOUNTR = KOUNTR +11
   END IF
   SLCG=DELTAT*CPW*WF
   SCONV=SQUG-QRSE15-SQUGW-SLCG
   WRITE(2,TEST)
   IF (MODE .EQ. 1 .OR. MODE .EQ. 2) THEN
       WRITE(2,1042) HCO2MH
       KOUNTR = KOUNTR+2
   END IF
   KOUNTR = KOUNTR + 13
   IF (IPLOP) THEN
        WRITE(2,1039) TCAB,TDEWC,CO2MMH
       KOUNTR = KOUNTR + 4
```

```
      END IF
      QLATTR = QLAT(1) + QLAT(5) + QLAT(2) + QLAT(3) + QLAT(6)
      IF(KOUNTR .EQ. 52) THEN
          WRITE(2,1015)
          KOUNTR = 6
      END IF
   50 IF(TRAN) GO TO 51
C     ASSIGN 58 TO IJM
C     ASSIGN 20 TO IJMP
C     GO TO 85
      DO 520 I=1,NMT
      IF(ABS(QVECT(I)).GT..05) GOTO 110
  520 CONTINUE
      GO TO 58
  110 CONTINUE
      IQ=-1
      QVECTT=0
      DO 521 I=1,NMT
  521 QVECTT=QVECTT+QVECT(I)**2
      IF(QVECTT .LT. QVECST) GO TO 111
      ICNTR=ICNTR+1
      IFLG=1
      IF(ICNTR .LT. 3 ) GO TO 112
      WRITE(2,1025)
      KOUNTR = KOUNTR + 1
  111 CONTINUE
      IFLG=0
      ICNTR=0
  112 CONTINUE
C     WRITE(2,OUT)
      IF(ICYCLE .LT. 20) GO TO 20
      WRITE(2,1027)
      KOUNTR = KOUNTR + 1
C     WRITE(2,OUT)
      GO TO 1
   51 CONTINUE
      IF(JT .EQ. 0 .OR. ENDONX)GO TO 53
      IXH=IXH+1
      IF(IXH .LE. JT)GO TO 52
      JT=0
      GO TO 53
   52 ENDONX=.TRUE.
      XHAT=XHATAR(IXH)
   53 CONTINUE
C
C  CHECK IF CRANE HAS SET THE FLAG ENDONX TO FALSE TO INDICATE THE
C  FINAL TIME VALUE SETI HAS BEEN REACHED
C
      IF(.NOT. ENDONX .AND. JT.EQ. 0) GO TO 58
      IF(ICOND.GT.0)GO TO 54
      IF(ABS(STORAT) .LT. 25.) PREC=4.
      IF(ABS(STORAT) .LT. 5.) PREC=5.
      IF(ABS(STORAT).LT.3.0)PREC=5.0
   54 CONTINUE
      IF(ICOND .NE. 0) GO TO 56
      IF(UASB .EQ. 0) GO TO 56
      QVECTT=0
      DO 505 I=1,NMT
```

```
      QVECTT=QVECTT+ QVECT(I)**2
  505 CONTINUE
      DO 506 I=1,NMT
      IF(ABS(QVECT(I)) .GT. .05) GO TO 20
  506 CONTINUE
      IF(QVECTT .LT. .01) GO TO 58
      GO TO 20
C-----------------
C  THE FOLLOWING LINES ARE NOT BEING USED UNTIL SATISFACTORY RESULTS
C  CAN BE OBTAINED FROM THE MATRIX INVERSION METHOD
C 55 CONTINUE
C     IF(ABS(STORAT) .GT. 5.) GO TO 20
C     IF(ABS((OLDSTR-STORAT)/STORAT) .GT. .0025) GO TO 20
C     TRAN=.FALSE.
C     GO TO 20
C --------------------
   56 CONTINUE
      IF(ICOND .EQ. 0) GO TO 57
      IF(STEPF .OR. CURVES) GO TO 20
   57 CONTINUE
      IF(TIME*60. .LT. 1.) GO TO 20
      IF(ABS(STORAT) .GT. 2.) GO TO 20
      IF (ABS((OLDSTR-STORAT)/STORAT) .LT. .001) GO TO 58
      GO TO 20
C
   58 PTIM =TIME*60.
      IF(KOUNTR .GT. 32)THEN
          WRITE(2,1015)
          KOUNTR = 6
      END IF
      WRITE(2,1016) PTIM,TGOUTS,SHSO,T(1),T(72),TISAV,TOSAV,QTSUIT,SQUG,
     $               QEVAP,TOTL,STORAT,QSHIV,QSTOR
      DELTAT = TWO - TWI
      SUBDT = SUBOUT - SUBIN
      OTPR=760.0/14.7*PH2OSO
      TDEWOT=DEWPT(OTPR)
      OTPRI=PG/(18.0/(WTMXD*SHSO)+1.0)*760.0/14.7
      TDWOT1=DEWPT(OTPRI)
      SATPRS=VPP(TGOUTS)
      RELHUM=PH2OSO/SATPRS
      IF(LCG) THEN
           WRITE(2,1036)TWI,TWO,DELTAT,TDEW,TGIN,TOTO2,TOTCO2,TOTWCN,
     $                 FDWTR,RM,WF
          KOUNTR = KOUNTR + 11
      END IF
      IF (MODE .EQ. 1 .OR. MODE .EQ. 2) WRITE(2,1042) HCO2MH
      KOUNT=KOUNT+1
      WRITE(2,TEST)
      WRITE(2,TSUIT)
C
C     WRITE(2,OUT)
C     CALL CLOCK(TIM)
C     WRITE(2,1000) TIM
C
      WRITE(2,1001) T
      IF(ICOND .NE. 0) GO TO 62
C
C  IF INITIAL CONDITIONS HAVE BEEN XQT AND NO MULTIPLE CASES ARE DESIRED
```

```
C  READ IMPOSED CONDITIONS
C
      IF (MCASES .EQ. 0) GO TO 1
      IF(.NOT. TERM) GO TO 61
   59 WRITE(2,1026)
   60 READ(1,INPUT,END=103)
C  60 READ(5,INPUT,END=103)
      KOUNT=KOUNT+1
      IF(KOUNT .GT. MCASES) GO TO 1
      GO TO 60
   61 CONTINUE
      IF (MCASES .EQ. 1) GO TO 67
C
C  IF STEP FUNCTIONS ARE DESIRED THE NEW CASE WILL CONTINUE WHERE THE
C  LAST CASE STOPPED
C
      IF(STEPF) GO TO 67
C
C  IF INITIAL CONDITIONS HAVE BEEN XQT AND MULTIPLE CASES ARE DESIRED SAVE
C  CURRENT VALUES FOR RESTARTS
C
      GO TO 63
C
C  IF IMPOSED CONDITIONS HAVE BEEN XQT AND NO MULTIPLE CASES DESIRED OR IF
C  AS MANY MULTIPLE CASES AS DESIRED HAVE BEEN XQT READ NEW INITIAL CONDITION
C
   62 IF (MCASES .LE. 1 .OR. KOUNT .GT. MCASES) GO TO 1
      IF(STEPF .AND. TERM) GO TO 59
      IF(STEPF) GO TO 67
C
C  IF IMPOSED CONDITIONS HAVE BEEN XQT AT LEAST ONCE AND AN ADDITIONAL IMPOSE
C  CASE IS DESIRED SET VALUES EQUAL TO SAVED VALUES
C
      GO TO 66
C
   63 DO 507 I=1,41
      SAVT(I)=T(I)
  507 CONTINUE
      SAVT(42)=T(72)
      SAVT(43)=T(73)
      DO 508 I=1,10
      SAVTOS(I)=TOS(I)
      SAVTIS(I)=TIS(I)
      SAVTUG(I)=TUG(I)
      STGOUT(I)=TGOUT(I)
      SAVTG(I)=TG(I)
      SAVTM(I)=TM(I)
  508 CONTINUE
      SWH2OO=WH2OO
      SWO2O=WO2OUT
      SWCO2O=WCO2O
      SWGOUT=WGOUT
      XTWO=TWO
      XSQUG=SQUG
      XQEVAP=QEVAP
      XTOTL=TOTL
      XQSHIV=QSHIV
      XSTRAT=STORAT
```

```
      XQSTOR=QSTOR
      XSCAB1=SCAB1
      XTOSAV=TOSAV
      XTISAV=TISAV
      XTGOS= TGOUTS
      XSHSO= SHSO
      XTHX=THX
      XTAVD=TAVD
      XTAVD2=TAVD2
      XTDUC2=TDUCT2
      XTDUCT=TDUCT
      XTPIPX=TPIPE
      XTPI2X=TPIPE2
      XTAVPX=TAVP
      XTAV2X=TAVP2
      IF(.NOT. IPLOP .AND. .NOT. TSAV ) GO TO 67
      IF(IPLOP) GO TO 64
      SWTH2O=VOLCAB*PCAB/(RGAS*(TCAB+460.))*SPHCAB*144.
      SCO2=VOLCAB*RHOCO2
      GO TO 65
   64 CONTINUE
      SWTH2O=T(62)
      SCO2=T(63)
   65 CONTINUE
      STCAB=TCAB
      STW=TW
      STDEWC=TDEWC
      GO TO 67
C
   66 DO 509 I=1,41
      T(I)=SAVT  (I)
  509 CONTINUE
      T(72)=SAVT(42)
      T(73)=SAVT(43)
      DO 510 I=1,10
      TOS(I)=SAVTOS(I)
      TIS(I)=SAVTIS(I)
      TUG(I)=SAVTUG(I)
      TGOUT(I)=STGOUT(I)
      TG(I)=SAVTG(I)
      TM(I)=SAVTM(I)
  510 CONTINUE
      WH2OO=SWH2OO
      WO2OUT=SWO2O
      WCO2O=SWCO2O
      WGOUT=SWGOUT
      TWO=XTWO
      SQUG=XSQUG
      QEVAP=XQEVAP
      TOTL=XTOTL
      QSHIV=XQSHIV
      QSTOR=XQSTOR
      STORAT=XSTRAT
      SCAB1=XSCAB1
      TOSAV=XTOSAV
      TISAV=XTISAV
      TGOUTS=XTGOS
      SHSO= XSHSO
```

```
      THX=XTHX
      TAVD=XTAVD
      TAVD2=XTAVD2
      TDUCT2=XTDUC2
      TDUCT=XTDUCT
      TPIPE=XTPIPX
      TPIPE2=XTPI2X
      TAVP=XTAVPX
      TAVP2=XTAV2X
      IF(.NOT. IPLOP .AND. .NOT. TSAV ) GO TO 67
      T(62)=SWTH2O
      T(63)=SCO2
      T(64)=STCAB
      T(65)=STW
      TCAB=STCAB
      TW=STW
      TDEWC=STDEWC
C
   67 CONTINUE
      MODEO=MODE
      IPLOPO=IPLOP
      READ(1,INPUT,END=103)
C     READ(5,INPUT,END=103)
C     WRITE(2,INPUT)
      IF(MODE .NE. 0 .OR. .NOT. IPLOP) GO TO 68
      IF(.NOT. IPLOPO) GO TO 68
      T(42)=T(62)
      T(43)=T(63)
      T(44)=T(64)
      T(45)=T(65)
   68 CONTINUE
      TRAN=.TRUE.
C
      WRITE(2,1017)
      ICOND=MIN0(ICOND+1,2)
      IF(.NOT. STEPF)ICOND=1
      EVA = .FALSE.
      IMPAIR = .FALSE.
      KOUNTR = 0
      GO TO 3
C
C  SHIRTSLEEVES HEADING
C
   69 WRITE(2,1037)
C
C  MAIN LOOP FOR SHIRTSLEEVE CASE
C
      PRNOW=TIME+PRINT
      NMT=41
      IF(.NOT. IPLOP) GO TO 70
      NMT=45
      IQV=42
      IF(ICOND .NE. 0 .AND. IPLOPO) GO TO 70
      T(44)=TCAB
      T(45)=TW
C
C  INITIAL VALUES FOR WEIGHT OF WATER VAPOR IN CABIN AND CO2 IN CABIN
C  DURING POSTLANDING
```

```
C
      T(IQV)=VOLCAB*PCAB/(RGAS*(TCAB+460.))*SPHCAB*144.
      T(IQV+1)=VOLCAB*RHOCO2
   70 PTIM =TIME*60.
      IF (.NOT. IMPAIR .AND. QSTOR .GT. 300) GO TO 71
      GO TO 74
   71 IMPAIR = .TRUE.
      IF (KOUNTR .GT. 24) GO TO 72
      WRITE(2,1028)
      WRITE(2,1029)
      GO TO 73
   72 WRITE(2,1002)
      WRITE(2,1029)
   73 WRITE(2,1030)
      KOUNTR = KOUNTR+24
   74 IF (IMPAIR .AND. QSTOR .GT. 1000) GO TO 75
      GO TO 78
   75 IF (KOUNTR .GT. 24) GO TO 76
      WRITE(2,1028)
      WRITE(2,1029)
      GO TO 77
   76 WRITE(2,1002)
      WRITE(2,1029)
   77 WRITE(2,1031)
      TERM=.TRUE.
      GO TO 95
   78 WRITE(2,1018)PTIM,TWO,T(1),T(72),TUGAV,SQUG,QEVAP,TOTL,STORAT,
     $            QSHIV,QSTOR,TCAB,TDEWC,CO2MMH
      IF(LCG) THEN
           WRITE(2,1036)TWI,TWO,DELTAT,TDEW,TGIN,TOTO2,TOTCO2,TOTWCN,
     $                  FDWTR,RM,WF
          KOUNTR = KOUNTR + 11
      END IF
      TMBF=0.0
      DO 511 I=2,38,4
      TMBF=TMBF+BF(I)
  511 CONTINUE
C     WRITE(2,RUN)
      KOUNTR = KOUNTR+1
   79 OLDSTR = STORAT
      IF(.NOT. CURVES) GO TO 81
      IF(ICOND .EQ. 0 .OR. .NOT. CMODE) GO TO 80
      CALL LAGIN(10,CCMODE,NPMODE,2,TIME,RMODE)
      MODEC=RMODE+.001
      IF(MODEC .EQ. MODE) GO TO 80
      KOUNTR=0
      WRITE(2,1002)
      MODEO=MODE
      MODE=MODEC
      GO TO 7
   80 CONTINUE
      IF (CTWI) CALL LAGIN(1,CCTWI,NPTWI,2,TIME,TWI)
      IF (CPCAB) CALL LAGIN(2,CCPCAB,NPPCAB,2,TIME,PCAB)
      IF (CRM  ) CALL LAGIN(3,CCRM,NPRM,2,TIME,RM)
      IF (CUEFF) CALL LAGIN(4,CCUEFF,NPUEFF,2,TIME,UEFF)
      IF (CWF  ) CALL LAGIN(5,CCWF,NPWF,2,TIME,WF)
      IF (CTDEWC)CALL LAGIN(6,CCTDWC,NPTDWC,2,TIME,TDEWC)
      IF (CTCAB) CALL LAGIN(7,CCTCAB,NPTCAB,2,TIME,TCAB)
```

```
      IF (CVCAB) CALL LAGIN(8,CCVCAB,NPVCAB,2,TIME,VCAB)
      IF (CTW)   CALL LAGIN(9,CCTW,NPTW,2,TIME,TW)
   81 CONTINUE
      IF(TRAN .OR. IQ.EQ. 0) GO TO 82
      CALL TMATRX
   82 CONTINUE
      CALL SHIRT
C
C  O2RATE & CO2RAT FOR SHIRTSLEEVE, JVI 11-8-89
      O2RATE= (0.0001708-((RQ-0.707)/0.273*0.0000123))*RM
      CO2RAT=O2RATE*44.0/32.0*RQ
      IF (KOUNTR .EQ. 50) GO TO 83
      GO TO 84
   83 WRITE(2,1037)
      KOUNTR = 6
   84 IF(TRAN) GO TO 89
C
C  CHECK QVECT FIRST TIME THROUGH AND AFTER EACH CALCULATION OF DELTA
C  TEMP'S FOR STEADY STATE CONDITIONS
C
      IF(IQ .NE. 0 .AND. IQ .NE. -1 ) GO TO 79
C
C     ASSIGN 95 TO IJM
C     ASSIGN 70 TO IJMP
C
   85 CONTINUE
      DO 512 I=1,NMT
      IF(ABS(QVECT(I)).GT..05) GOTO 86
  512 CONTINUE
      GO TO 95
   86 CONTINUE
      IQ=-1
      QVECTT=0
      DO 513 I=1,NMT
  513 QVECTT=QVECTT+QVECT(I)**2
      IF(QVECTT .LT. QVECST) GO TO 87
      ICNTR=ICNTR+1
      IFLG=1
      IF(ICNTR .LT. 3 ) GO TO 88
      WRITE(2,1025)
      KOUNTR = KOUNTR + 1
   87 CONTINUE
      IFLG=0
      ICNTR=0
   88 CONTINUE
C
C     WRITE(2,OUT)
C
      IF(ICYCLE .LT. 20) GO TO 70
      WRITE(2,1027)
      KOUNTR = KOUNTR + 1
C
C     WRITE(2,OUT)
C
      GO TO 1
   89 CONTINUE
      GO TO 90
C -----------------
```

```
C   THE FOLLOWING LINES ARE NOT BEING USED UNTIL SATISFACTORY
C   RESULTS CAN BE OBTAINED FROM THE MATRIX INVERSION
C   METHOD.
C     IF(ICOND .NE. 0 .OR. ABS(STORAT) .GT. 5.) GO TO 90
C      IF(ABS((OLDSTR-STORAT)/STORAT).GE. .0025) GO TO 70
C     TRAN=.FALSE.
C     GO TO 70
C -------------------
   90 CONTINUE
      IF(JT .EQ. 0  .OR. ENDONX)GO TO 92
      IXH=IXH+1
      IF(IXH .LE. JT)GO TO 91
      JT=0
      GO TO 92
   91 ENDONX=.TRUE.
      XHAT=XHATAR(IXH)
   92 CONTINUE
      IF(TIME*60. .LT. 1.) GO TO 94
      IF(ABS(STORAT) .LT. 25.) PREC=4.
      IF(ABS(STORAT) .LT. 5.) PREC=5.
      IF(ICOND .EQ. 0) GO TO 93
      IF(STEPF .OR. CURVES) GO TO 94
   93 CONTINUE
      IF (ABS(STORAT) .GT. 2.) GO TO 94
      IF (ABS((OLDSTR-STORAT)/STORAT) .LT. .001) GO TO 95
C
C     CHECK IF CRANE HAS SET THE FLAG ENDONX TO FALSE TO INDICATE THE
C     FINAL TIME VALUE SETI HAS BEEN REACHED
C
   94 IF(.NOT. ENDONX .AND. JT .EQ. 0) GO TO 95
      IF(PRNOW .GT. TIME) GO TO 79
      PRNOW=PRNOW+PRINT
      GO TO 70
C
   95 PTIM=TIME*60.
      WRITE(2,1018) PTIM,TWO,T(1),T(72),TUGAV,SQUG,QEVAP,TOTL,STORAT,
     $              QSHIV1,QSTOR,TCAB,TDEWC,CO2MMH
      KOUNTR = KOUNTR+1
      IF(LCG) THEN
          WRITE(2,1036) TWI,TWO,DELTAT,TDEW,TGIN,TOTO2,TOTCO2,TOTWCN,
     $                  FDWTR,RM,WF
         KOUNTR = KOUNTR + 11
      END IF
      TMBF=0.0
      DO 514 I=2,38,4
      TMBF=TMBF+BF(I)
  514 CONTINUE
C     WRITE(2,RUN)
      WRITE(2,TEST)
      KOUNT = KOUNT + 1
C
C     WRITE(2,OUT)
C     CALL CLOCK(TIM)
C     WRITE(2,1000) TIM
C
      WRITE(2,1001) T
      KOUNTR = KOUNTR + 19
      IF(ICOND .NE. 0) GO TO 96
```

```
C
C     IF INITIAL CONDITIONS HAVE BEEN XQT AND NO MULTIPLE CASES ARE DESIRED
C     READ IMPOSED CONDITIONS
C
      IF (MCASES .EQ. 0) GO TO 1
      IF(TERM) GO TO 59
      IF (MCASES .EQ. 1) GO TO 101
C
C     IF STEP FUNCTIONS ARE DESIRED THE NEW CASE WILL CONTINUE WHERE THE
C     LAST CASE STOPPED
C
      IF(STEPF) GO TO 101
C
C     IF INITIAL CONDITIONS HAVE BEEN XQT AND MULTIPLE CASES ARE DESIRED SAVE
C     CURRENT VALUES FOR RESTARTS
C
      GO TO 97
C
C     IF IMPOSED CONDITIONS HAVE BEEN XQT AND NO MULTIPLE CASES DESIRED OR IF
C     AS MANY MULTIPLE CASES AS DESIRED HAVE BEEN XQT READ NEW INITIAL CONDITION
C
   96 IF (MCASES .LE. 1 .OR. KOUNT .GT. MCASES) GO TO 1
      IF(STEPF .AND. TERM) GO TO 59
      IF(STEPF) GO TO 101
C
C     IF IMPOSED CONDITIONS HAVE BEEN XQT AT LEAST ONCE AND AN ADDITIONAL IMPOSE
C     CASE IS DESIRED SET VALUES EQUAL TO SAVED VALUES
C
      GO TO 100
   97 DO 516 I=1,41
      SAVT(I)=T(I)
  516 CONTINUE
      SAVT(42)=T(72)
      SAVT(43)=T(73)
      DO 517 I=1,10
      SAVTUG(I)=TUG(I)
  517 CONTINUE
      XTWO=TWO
      XTUGAV=TUGAV
      XSQUG=SQUG
      XQEVAP=QEVAP
      XTOTL=TOTL
      XSTRAT=STORAT
      XQSHIV=QSHIV
      XQSTOR=QSTOR
      SDENSC=DENSC
      IF(.NOT. IPLOP .AND. .NOT. TSAV ) GO TO 101
      IF(IPLOP) GO TO 98
      SWTH2O=VOLCAB*PCAB/(RGAS*(TCAB+460.))*SPHCAB*144.
      SCO2=VOLCAB*RHOCO2
      GO TO 99
   98 CONTINUE
      SWTH2O=T(42)
      SCO2=T(43)
   99 CONTINUE
      STCAB = TCAB
      STW=TW
      STDEWC = TDEWC
```

```
      GO TO 101
C
  100 DO 518 I=1,41
      T(I)=SAVT(I)
  518 CONTINUE
      T(73)=SAVT(43)
      T(72)=SAVT(42)
      DO 519 I=1,10
      TUG(I)=SAVTUG(I)
  519 CONTINUE
      TWO=XTWO
      TUGAV=XTUGAV
      SQUG=XSQUG
      QEVAP=XQEVAP
      TOTL=XTOTL
      STORAT=XSTRAT
      QSHIV=XQSHIV
      QSTOR=XQSTOR
      DENSC =SDENSC
      IF(.NOT. IPLOP .AND. .NOT. TSAV ) GO TO 101
      T(42)=SWTH2O
      T(43)=SCO2
      T(44)=STCAB
      T(45)=STW
      TW=STW
      TCAB = STCAB
      TDEWC = STDEWC
  101 CONTINUE
      MODEO=MODE
      IPLOPO=IPLOP
      READ(1,INPUT,END=103)
C     READ(5,INPUT,END=103)
C
C     WRITE(2,INPUT)
C
      IF(MODE .LT. 1 .OR. .NOT. IPLOP) GO TO 102
      IF(.NOT. IPLOPO) GO TO 102
      T(62)=T(42)
      T(63)=T(43)
      T(64)=T(44)
      T(65)=T(45)
  102 CONTINUE
      WRITE(2,1017)
      ICOND=MIN0(ICOND+1,2)
      IF(.NOT. STEPF)ICOND=1
      IMPAIR = .FALSE.
      KOUNTR=0
      TRAN=.TRUE.
      GO TO 3
 1000 FORMAT(' TIME',E15.7)
 1001 FORMAT(' T=',4E15.7)
 1002 FORMAT(1H1)
 1003  FORMAT(1H1,17X,18HINITIAL CONDITIONS//)
 1004  FORMAT(23X,3HMAN/
     $      50H METABOLIC ACTIVITY LEVEL, BTU/HR---------------- ,F9.3/
     $      50H USEFUL WORK EFFICIENCY, PERCENT----------------- ,F9.3/
     $      50H CONVECTIVE AREA OF MAN, SQ FT------------------- ,F9.3/
     $      50H RADIATIVE AREA OF MAN, SQ FT-------------------- ,F9.3/
```

```
    $      50H HEIGHT OF MAN,  IN------------------------------ ,F9.3/
    $      50H WEIGHT OF MAN,  LB------------------------------ ,F9.3)
1005  FORMAT(1H0,22X,5HCABIN)
1006 FORMAT(50H VIEW FACTOR------------------------------------- ,F9.3)
1007  FORMAT(21H Q ABSORBED PER SQ FT/
    $       50H         TORSO ---------------------------------- ,F9.3/
    $       50H         RIGHT SLEEVE --------------------------- ,F9.3/
    $       50H         LEFT SLEEVE ---------------------------- ,F9.3/
    $       50H         RIGHT LEG ------------------------------ ,F9.3/
    $       50H         LEFT LEG ------------------------------- ,F9.3/
    $       50H         RIGHT GLOVE ---------------------------- ,F9.3/
    $       50H         LEFT GLOVE ----------------------------- ,F9.3/
    $       50H         RIGHT BOOT ----------------------------- ,F9.3/
    $       50H         LEFT BOOT ------------------------------ ,F9.3/
    $       50H         HELMET --------------------------------- ,F9.3)
1008 FORMAT(50H CABIN ATMOSPHERIC TEMPERATURE, F---------------- ,F9.3/
    $       50H EFFECTIVE WALL TEMPERATURE, F------------------- ,F9.3/
    $       50H FREESTREAM VELOCITY, FT/MIN--------------------- ,F9.3/
    $       50H CABIN PRESSURE, PSIA---------------------------- ,F9.3)
1009 FORMAT(50H DEWPOINT TEMPERATURE IN CABIN, F---------------- ,F9.3/
    $       50H G  --------------------------------------------- ,F9.3)
1010  FORMAT(1H0,19X,12HUNDERGARMENT/
    $       50H THICKNESS OF UNDERGARMENT----------------------- ,F9.3/
    $       50H CONDUCTIVITY OF UNDERGARMENT-------------------- ,F9.3/
    $       50H EMISSIVITY OF UNDERGARMENT---------------------- ,F9.3)
1011  FORMAT(1H0,16X,21HLIQUID COOLED GARMENT/
    $       50H LIQUID COOLANT FLOW RATE, LB/HR----------------- ,F9.3/
    $       50H TEMPERATURE OF LIQUID COOLANT IN---------------- ,F9.3/
    $       50H SPECIFIC HEAT OF COOLANT------------------------ ,F9.3/
    $       50H UA OF LIQUID COOLED GARMENT--------------------- ,F9.3)
1012  FORMAT(1H0,18X,13HPRESSURE SUIT)
1013 FORMAT(55H PURGE FLOW--------------------------------------  YES)
1014 FORMAT(50H SUIT LOOP FLOW, CFM ---------------------------- ,F9.3/
    $       50H SPECIFIC HEAT OF GAS --------------------------- ,F9.3/
    $       50H TEMPERATURE OF GAS INTO SUIT ------------------- ,F9.3/
    $       50H DEWPOINT TEMPERATURE AT SUIT INLET, F ---------- ,F9.3/
    $       50H TOTAL SUIT PRESSURE, PSIA IT INLET, F ---------- ,F9.3/
    $       50H PARTIAL PRESSURE OF OXYGEN IN SUIT, PSIA ------- ,F9.3/
    $       50H0RADIATIVE AREA OF SUIT COMPONENTS, SQ FT             /
    $       50H         TORSO ---------------------------------- ,F9.3/
    $       50H         EACH SLEEVE ---------------------------- ,F9.3/
    $       50H         EACH LEG ------------------------------- ,F9.3/
    $       50H         HELMET --------------------------------- ,F9.3/
    $       50H         EACH GLOVE ----------------------------- ,F9.3/
    $       50H         EACH BOOT ------------------------------ ,F9.3)
1015  FORMAT(1H1,' TIME,    TEMP   S/H AT    TEMP    AV TEMP  AV TEMP
    $AV TEMP  Q THRU  Q SENSIBLE  QEVAP  Q LATENT  HEAT    SHIVER   TOT
    $AL  ','/,'    MIN      GAS    SUIT  HEAD CORE   SKIN    INSIDE   O
    $UTSIDE    SUIT   TOTAL     BTU/HR   BTU/HR  STORAGE   RATE    HEAT
    $   ','/,'             OUT,  OUTLET     F       F      OF SUIT  OF
    $ SUIT  BTU/HR  BTU/HR                        RATE    BTU/HR   STORA
    $GE  ','/,'             F                                  F
    $  F                                          BTU/HR              BTU
    $      '//)
1016  FORMAT(F8.1,F9.2,F9.3,11F9.2)
1017  FORMAT(1H1,17X,18HIMPOSED CONDITIONS)
1018  FORMAT(F8.1,13F9.2)
1019  FORMAT(18X,17HSHIRTSLEEVES MODE/)
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 1020  FORMAT(18X,18HNORMAL SUITED MODE/)
 1021  FORMAT(21X, 8HEVA MODE/)
 1022  FORMAT(13X,27HSUITED WITH HELMET OFF MODE/)
 1023 FORMAT(' CURVES CANNOT BE TRUE WITH POSTLANDING OPTION, CURVES SET
     $ FALSE')
 1024 FORMAT(' UASB CANNOT BE GREATER THAN ZERO WITH THE POSTLANDING OPT
     $ION, UASB SET TO ZERO')
 1025 FORMAT(' THE CUTBACK VARIATIONS HAVE BEEN TRIED')
 1026 FORMAT(1X,129(1H*)/' NO MORE IMPOSED CASES ARE RUN IF VITAL FUNCTI
     $ONS ARE TERMINATED, THE INPUT DATA IS SEARCHED AHEAD FOR A NEW INI
     $TIAL CASE')
 1027 FORMAT(' STEADY STATE DID NOT CONVERGE IN MAIN')
 1028 FORMAT(1H0)
C     LIFE FUNCTIONS
 1029 FORMAT(5X,'XX       XX  XXXXXXX  XXXXXXX          XXXXXXX   '
     &,'XX   XX  XX     XX    XXXXXX   XXXXXXXX  XX   XXXXX   XX     '
     &,'XX   XXXXX '
     &,/5X,'XX       XX  XXXXXXX  XXXXXXX          XXXXXXX  XX   XX  XX'
     &,'     XX   XXXXXXXX  XXXXXXXX  XX  XXXXXXX  XX     XX  XXXXXXX  '
     &,/5X,'XX       XX  XX       XX               XX       XX   XX  XX'
     &,'X    XX   XX           XX     XX  XX   XX  XXX    XX  XX       '
     &,/5X,'XX       XX  XX       XX               XX       XX   XX  XX'
     &,'XX   XX   XX           XX     XX  XX   XX  XXXX   XX  XXXXXX   '
     &,/5X,'XX       XX  XXXXX    XXXXX            XXXXX    XX   XX  XX'
     &,' XX  XX   XX           XX     XX  XX   XX  XX XX  XX   XXXXXX  '
     &,/5X,'XX       XX  XXXXX    XXXXX            XXXXX    XX   XX  XX'
     &,'  XX XX   XX           XX     XX  XX   XX  XX  XX XX       XX  '
     &,/5X,'XX       XX  XX       XX               XX       XX   XX  XX'
     &,'   XXXX   XX           XX     XX  XX   XX  XX   XXXX       XX  '
     &,/5X,'XXXXXXX  XX  XX       XXXXXXX          XX       XXXXXXX  XX'
     &,'    XXX   XXXXXXXX     XX     XX  XXXXXXX  XX    XXX  XXXXXXX  '
     &,/5X,'XXXXXXX  XX  XX       XXXXXXX          XX        XXXXX   XX'
     &,'     XX   XXXXXX       XX     XX   XXXXX   XX     XX   XXXXX'//)
C     IMPAIRED
 1030 FORMAT(30X,'XX  XX     XX  XXXXXXX    XXXXXX   XX  XXXXXXX   XXX'
     &,'XXXX  XXXXXXX                                                  '
     &,/30X,'XX  XXX   XXX  XXXXXXXX  XXXXXXXX  XX  XXXXXXXX  XXXXXXX  '
     &,'XXXXXXXX                                                       '
     &,/30X,'XX  XXXX XXXX  XX    XX  XX    XX  XX  XX    XX  XX       '
     &,'XX    XX                                                       '
     &,/30X,'XX  XX XXX XX  XX    XX  XX    XX  XX  XX    XX  XX       '
     &,'XX    XX                                                       '
     &,/30X,'XX  XX  X  XX  XXXXXXXX  XXXXXXXX  XX  XXXXXXXX  XXXXX    '
     &,'XX    XX                                                       '
     &,/30X,'XX  XX     XX  XXXXXXX   XXXXXXXX  XX  XXXXXXX   XXXXX    '
     &,'XX    XX                                                       '
     &,/30X,'XX  XX     XX  XX        XX    XX  XX  XX  XX    XX       '
     &,'XX    XX                                                       '
     &,/30X,'XX  XX     XX  XX        XX    XX  XX  XX   XX   XXXXXXX  '
     &,'XXXXXXXX                                                       '
     &,/30X,'XX  XX     XX  XX        XX    XX  XX  XX    XX  XXXXXXX  '
     &,'XXXXXXX            '///)
C     TERMINATED
 1031 FORMAT(15X,'XXXXXXXX  XXXXXXX  XXXXXXX   XX     XX  XX  XX     X'
     &,'X   XXXXXX   XXXXXXXX  XXXXXXX  XXXXXXX                        '
     &,/15X,'XXXXXXXX  XXXXXXX  XXXXXXXX  XXX   XXX  XX  XX     XX  '
     &,'XXXXXXXX  XXXXXXXX  XXXXXXX  XXXXXXXX                          '
     &,/15X,'   XX     XX       XX     XX  XXXX XXXX  XX  XXX     XX  XX '
```

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    &,'   XX     XX     XX       XX    XX                              '
    &,/15X,'   XX     XX       XX    XX  XX XXX XX  XX  XXXX   XX  XX '
    &,'   XX     XX     XX       XX    XX                              '
    &/15X,'   XX     XXXXX    XXXXXXXX  XX  X  XX  XX  XX XX  XX  XXXX'
    &,'XXXX     XX     XXXXX    XX    XX                              '
    &/15X,'   XX     XXXXX    XXXXXXX   XX     XX  XX  XX  XX XX  XXXX'
    &,'XXXX     XX     XXXXX    XX    XX                              '
    &/15X,'   XX     XX       XX  XX    XX     XX  XX  XX   XXXX  XX  '
    &,'  XX     XX     XX       XX    XX                              '
    &/15X,'   XX     XXXXXXX  XX   XX   XX     XX  XX  XX    XXX  XX  '
    &,'  XX     XX     XXXXXXX  XXXXXXXX                              '
    &/15X,'   XX     XXXXXXX  XX    XX  XX     XX  XX  XX      XX  XX  '
    &,'  XX     XX     XXXXXXX  XXXXXXX           '///)
1032 FORMAT(50H0CONVECTIVE AREA OF SUIT COMPONENTS, SQ FT             /
    $       50H          TORSO ---------------------------------- ,F9.3/
    $       50H          EACH SLEEVE ---------------------------- ,F9.3/
    $       50H          EACH LEG ------------------------------- ,F9.3/
    $       50H          HELMET --------------------------------- ,F9.3/
    $       50H          EACH GLOVE ----------------------------- ,F9.3/
    $       50H          EACH BOOT ------------------------------ ,F9.3/
    $       50H0WEIGHT OF SUIT COMPONENTS                             /
    $       50H          TORSO ---------------------------------- ,F9.3/
    $       50H          EACH SLEEVE ---------------------------- ,F9.3/
    $       50H          EACH LEG ------------------------------- ,F9.3/
    $       50H          HELMET --------------------------------- ,F9.3/
    $       50H          EACH GLOVE ----------------------------- ,F9.3/
    $       50H          EACH BOOT ------------------------------ ,F9.3)
1033 FORMAT(50H0SPECIFIC HEAT OF SUIT COMPONENTS                      /
    $       50H          TORSO ---------------------------------- ,F9.3/
    $       50H          EACH SLEEVE ---------------------------- ,F9.3/
    $       50H          EACH LEG ------------------------------- ,F9.3/
    $       50H          HELMET --------------------------------- ,F9.3/
    $       50H          EACH GLOVE ----------------------------- ,F9.3/
    $       50H          EACH BOOT ------------------------------ ,F9.3/
    $       50H0THICKNESS OF SUIT COMPONENTS, FT                      /
    $       50H          TORSO ---------------------------------- ,F9.3/
    $       50H          EACH SLEEVE ---------------------------- ,F9.3/
    $       50H          EACH LEG ------------------------------- ,F9.3/
    $       50H          HELMET --------------------------------- ,F9.3/
    $       50H          EACH GLOVE ----------------------------- ,F9.3/
    $       50H          EACH BOOT ------------------------------ ,F9.3)
1034 FORMAT(50H0CONDUCTIVITY OF SUIT COMPONENTS                       /
    $       50H          TORSO ---------------------------------- ,F9.3/
    $       50H          EACH SLEEVE ---------------------------- ,F9.3/
    $       50H          EACH LEG ------------------------------- ,F9.3/
    $       50H          HELMET --------------------------------- ,F9.3/
    $       50H          EACH GLOVE ----------------------------- ,F9.3/
    $       50H          EACH BOOT ------------------------------ ,F9.3/
    $       50H0EMISSIVITY OF INNER SURFACE OF SUIT COMPONENTS        /
    $       50H          TORSO ---------------------------------- ,F9.3/
    $       50H          EACH SLEEVE ---------------------------- ,F9.3/
    $       50H          EACH LEG ------------------------------- ,F9.3/
    $       50H          HELMET --------------------------------- ,F9.3/
    $       50H          EACH GLOVE ----------------------------- ,F9.3/
    $       50H          EACH BOOT ------------------------------ ,F9.3)
1035 FORMAT(50H0EMISSIVITY OF OUTER SURFACE OF SUIT COMPONENTS        /
    $       50H          TORSO ---------------------------------- ,F9.3/
    $       50H          EACH SLEEVE ---------------------------- ,F9.3/
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     $       50H         EACH LEG ------------------------------- ,F9.3/
     $       50H         HELMET ---------------------------------- ,F9.3/
     $       50H         EACH GLOVE ----------------------------- ,F9.3/
     $       50H         EACH BOOT ------------------------------ ,F9.3)
 1036 FORMAT(5X,36HLCG INLET WATER TEMPERATURE ------- ,F9.3,4H  0F/
     $5X,36HLCG OUTLET WATER TEMPERATURE ------ ,F9.3,8H  0F    /
     $5X,36HLCG WATER TEMPERATURE DIFFERENCE -- ,F9.3,8H  0F    /
     $5X,36HSUIT INLET DEWPOINT TEMPERATURE --- ,F9.3,8H  0F    /
     $5X,36HSUIT INLET DRY BULB TEMPERATURE --- ,F9.3,8H  0F    /
     $5X,36HOXYGEN USED ----------------------- ,F9.3,8H  LBS   /
     $5X,36HCO2 PRODUCED ---------------------- ,F9.3,8H  LBS   /
     $5X,36HTOTAL WATER EVAPORATION FROM BODY - ,F9.3,8H  LBS   /
     $5X,36HFEED WATER USED ------------------- ,F9.3,8H  LBS   /
     $5X,36HMETABOLIC RATE -------------------- ,F9.3,8H  BTU/HR/
     $5X,36HWATER FLOW RATE ------------------- ,F9.3,8H  LB/HR )
 1037 FORMAT(1H1,'  TIME,    TEMP    TEMP    AV TEMP   TEMP        Q
     $    Q EVAP  Q LATENT   HEAT    SHIVER     TOTAL  CABIN     DEW
     $ CO2,', /, '    MIN    WATER    HEAD     SKIN,   UNDER-   SENSIBLE
     $ BTU/HR   BTU/HR  STORAGE    RATE      HEAT   TEMP     POINT   PRE
     $SS', /, '            OUT,    CORE       F     GARMENT   BTU/HR
     $                   RATE    BTU/HR     STORAGE  F        F     MM
     $HG', /, '             F        F                  F
     $                  BTU/HR              BTU', //)
 1038 FORMAT(18X,12HPOST LANDING)
 1039 FORMAT(15H   CABIN TEMP =,F7.2, 6H DEG F,18H   DEWPOINT TEMP =,
     $       F7.2, 6H DEG F,17H   CO2 PRESSURE =,F7.2, 6H MM HG/)
 1040 FORMAT(' ATMOSPHERIC GAS CONSTANT, LBF-FT/(LBM-DEG R)-----',F9.3/
     $       ' DRYBULB TEMP. OF ATMOSPHERE, DEG.F---------------',F9.3/
     $       ' VOLUME OF CABIN, CU FT--------------------------',F9.3/
     $       ' ATMOSPHERIC OXYGEN PARTIAL PRESSURE, PSIA--------',F9.3/
     $       ' ATMOSPHERIC NYTROGEN PARTIAL PRESSURE, PSIA------',F9.3/
     $       ' SPECIFIC HEAT OF ATMOSPHERE, BTU/(LBM-DEG F)-----',F9.3/
     $       ' NUMBER OF MEN------------------------------------',I9/
     $       ' ATMOSPHERIC PRESSURE, PSIA-----------------------',F9.3/
     $       ' CABIN WALL AREA, SQ FT---------------------------',F9.3/
     $       ' DEWPOINT TEMP. OF ATMOSPHERE, DEG F--------------',F9.3/
     $       ' POSTLANDING FAN CIRCULATION, CFM-----------------',F9.3/)
 1041 FORMAT(50H0MAXIMUM RUN TIME, MINUTES----------------------- ,F9.3)
 1042 FORMAT(5X,34H PARTIAL PRESSURE OF CO2 IN HELMET,F12.6, 7H  MM HG/)
 1043  FORMAT(23X,3HMAN/
     $      50H EFFECTIVE METABOLIC ACTIVITY LEVEL, BTU/HR------ ,F9.3/
     $      50H USEFUL WORK EFFICIENCY, PERCENT----------------- ,F9.3/
     $      50H CONVECTIVE AREA OF MAN, SQ FT------------------- ,F9.3/
     $      50H RADIATIVE AREA OF MAN, SQ FT-------------------- ,F9.3/
     $      50H HEIGHT OF MAN,  IN------------------------------ ,F9.3/
     $      50H WEIGHT OF MAN,  LB------------------------------ ,F9.3)
 103  CONTINUE
C
C UNIX 8/00, JVI
      CLOSE (2)
      END
```

J.2 SUBROUTINE BODYSZ

```
      SUBROUTINE BODYSZ(MODEBZ,CBZ,RMBZ,ACBZ,ARBZ,ACSBZ,ARSBZ,
     $                  WSBZ)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                  C
C SUBROUTINE BODYSZ USES INPUT VARIABLES HEIGHT AND WEIGHT IN      C
C NOMOGRAPHIC RELATIONSHIPS DESCRIBED IN "A MODEL OF HEAT TRANSFER C
C IN IMMERSED MAN," BY L.D. MONTGOMERY (ANN. BIOMED. ENG. 1974, 2: C
C 19-46) TO PROPORTIONALIZE THE FOLLOWING VARIABLES ACCORDING TO   C
C BODY SIZE: THERMAL CAPACITANCE AND CONDUCTANCE, BASAL METABOLIC  C
C AND BLOOD FLOW RATES, AND THE LENGTHS AND RADII OF BODY COMPART- C
C MENTS.  IF AVRM IS SET TO .TRUE. THE METABOLIC RATE IS ALSO      C
C PROPORTIONALIZED FOR BODY SIZE, OTHERWISE IT IS ASSUMED TO BE    C
C ABSOLUTE.                                                        C
C                                                  C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      LOGICAL AVRM
      DIMENSION SWT(50), WTFACT(50), BFBFAC(40),SAFACT(10),
     $          VOLC(40), DEPTC(10), RADC(40), RADCM(40),
     $          SKINL(10),CBZ(41),ACSBZ(10),ARSBZ(10),WSBZ(10),
     $          SKINR(10),RSKINA(10),COMSAI(10)
      COMMON/BSIZE/BRM,QB(40),BFB(40),FACTOR(40),WMUSC,WSKIN
      COMMON/NOMO/HEIGHT,WEIGHT,AVRM
      COMMON/RATCO/RCOEF1(10),RCOEF2(10),RCOEF3(10)
      COMMON/RATSH/RSHCO1(10),RSHCO2(10)
      DATA WTFACT/0.019292,0.028232,0.00588,0.0333,0.00423,
     $            0.04704,0.18704,0.2834,0.6333,0.0213,
     $            0.011878,0.005882,0.02664,0.04335,0.00382,
     $            0.011878,0.005882,0.02664,0.04335,0.00382,
     $            0.039584,0.015176,0.0805,0.10665,0.00947,
     $            0.039584,0.015176,0.0805,0.10665,0.00947,
     $            0.001824,0.0002352,0.000594,0.006665,0.00147,
     $            0.001824,0.0002352,0.000594,0.006665,0.00147,
     $            0.002942,0.0004706,0.000594,0.01,0.00188,
     $            0.002942,0.0004706,0.000594,0.01,0.00188/
      DATA BFBFAC/45.0,1.2,1.2,5.34,210.0,1.2,1.2,1.56,
     $            1.2,1.2,1.2,1.35,1.2,1.2,1.2,1.35,
     $            1.2,1.2,1.2,0.84,1.2,1.2,1.2,0.84,
     $            1.2,1.2,1.2,5.58,1.2,1.2,1.2,5.58,
     $            1.2,1.2,1.2,2.34,1.2,1.2,1.2,2.34/
      DATA SAFACT/0.07,0.3602,0.06705,0.06705,0.1587,0.1587,
     $            0.025,0.025,0.0343,0.0343/
      DATA CONFAC/2.204585/,CNFAC1/3.968254/,CNFAC2/2.204623/
      DATA SKINL/12.5,60.0,56.0,56.0,80.0,80.0,
     $           48.0,48.0,62.5,62.5/
      DATA SKINR/10.22,14.7,5.02,5.02,6.42,6.42,
     $           1.49,1.49,1.57,1.57/
      DATA COMSAI/1268.15,6525.52,1214.70,1214.70,2875.07,
     $            2875.07,452.91,452.91,621.39,621.39/
      SAVE
C
C
      BHT=HEIGHT*2.54
      BWT=WEIGHT*453.59237
      SG=0.8*(BHT**0.242/BWT**0.1)+0.162
      PBF=5.548/SG-5.044
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```
      BFWT=PBF*BWT
      BLWT=BWT-BFWT
      TA=BFWT*0.001
      TNA=BLWT*0.001
      SA=71.84*(BWT/1000.0)**0.425*BHT**0.725
      ACBZ=SA/929.0304
      ARBZ=ACBZ
      IF(MODEBZ.EQ.0) ARBZ=15.5/19.5*ACBZ
      IF(AVRM)RMBZ=RMBZ*(WEIGHT/154)**0.75
C
C  CALCULATE WEIGHTS AND THERMAL CAPACITANCES OF BODY COMPARTMENTS
C
       DO 1110 I=1,10
          M=5*I-4
          SWT(M)=WTFACT(M)*TNA
          SWT(M+1)=WTFACT(M+1)*TNA
          SWT(M+2)=WTFACT(M+2)*TNA
          SWT(M+3)=WTFACT(M+3)*TA
          SWT(M+4)=WTFACT(M+4)*TNA
          N=4*I-3
          CBZ(N)=(0.5*SWT(M)+0.9*SWT(M+1))*CONFAC
          IF(I.EQ.2) CBZ(N)=CBZ(N)-2.25*CONFAC
          CBZ(N+1)=0.9*SWT(M+2)*CONFAC
          CBZ(N+2)=0.6*SWT(M+3)*CONFAC
          CBZ(N+3)=0.9*SWT(M+4)*CONFAC
 1110 CONTINUE
      CBZ(41)=2.25*CONFAC
C
C  CALCULATE  BASAL METABOLIC AND BLOOD FLOW RATES OF BODY COMPARTMENTS
C
      BM=38.67*0.0001
      BRM=BM*SA*CNFAC1
      WCORE=0.1765*TNA+0.2588*TNA
      WMUSC=0.5058*TNA
      WFAT=1.0*TA
      WSKIN=0.05882*TNA
      WSF=WSKIN+WFAT
      QSF=0.3*WSF
      QM=(0.18*BM*SA)-QSF
      QC=0.1*BM*SA
      DO 1111 I=1,10
          M=5*I-4
          N=4*I-3
          QB(N)=((SWT(M)+SWT(M+1))*QC/WCORE)*CNFAC1
          IF(I.EQ.1) QB(N)=QB(N)+0.16*BM*SA*CNFAC1
          IF(I.EQ.2) QB(N)=QB(N)+0.56*BM*SA*CNFAC1
          QB(N+1)=(SWT(M+2)*QM/WMUSC)*CNFAC1
          QB(N+2)=(SWT(M+3)*QSF/WSF)*CNFAC1
          QB(N+3)=(SWT(M+4)*QSF/WSF)*CNFAC1
          BFB(N)=BFBFAC(N)*QB(N)*CNFAC2/CNFAC1
          IF(I.LE.2) BFB(N)=BFBFAC(N)*CNFAC2
          BFB(N+1)=BFBFAC(N+1)*QB(N+1)*CNFAC2/CNFAC1
          BFB(N+2)=BFBFAC(N+2)*QB(N+2)*CNFAC2/CNFAC1
          BFB(N+3)=BFBFAC(N+3)*SWT(M+4)*CNFAC2/CNFAC1
 1111 CONTINUE
C
C  CALCULATE RADII AND LENGTHS OF BODY COMPARMENTS
C
```

```
      DO 1112 I=1,10
         M=5*I-4
         N=4*I-3
         VOLC(N)=(SWT(M)+SWT(M+1))*1000.0
         VOLC(N+1)=VOLC(N)+SWT(M+2)*1000.0
         VOLC(N+2)=VOLC(N+1)+SWT(M+3)*1000.0
         VOLC(N+3)=VOLC(N+2)+SWT(M+4)*1000.0
         COMSA=SAFACT(I)*SA
         DEPTC(I)=COMSA**2/(4.0*3.1416*VOLC(N+3))
         J=4*I
         DO 1113 K=N,J
            RADC(K)=SQRT(VOLC(K)/(3.1416*DEPTC(I)))
 1113    CONTINUE
         IM=I-1
         IF(I.EQ.1) IM=10
         IF(MODEBZ.GT.0)GO TO 1114
         RSHCO1(IM)=(1.0/SQRT(2.0*RADC(J)))/(1.0/SQRT(2.0*SKINR(I)))
         RSHCO2(IM)=(3.5/DEPTC(I))**0.25/(3.5/SKINL(I))**0.2
         GO TO 1112
 1114    RCOEF1(IM)=(3.5/DEPTC(I))**(1.0/3.0)/(3.5/SKINL(I))**(1.0/3.0)
         RCOEF2(IM)=(1.0/SQRT(2.0*RADC(J)+0.222))/
     $               (1.0/SQRT(2.0*SKINR(I)+0.222))
         RCOEF3(IM)=(3.5/DEPTC(I))**0.25/(3.5/SKINL(I))**0.25
         RSKINA(IM)=COMSA/COMSAI(I)
         ACSBZ(IM)=ACSBZ(IM)*RSKINA(IM)
         ARSBZ(IM)=ARSBZ(IM)*RSKINA(IM)
         WSBZ(IM)=WSBZ(IM)*RSKINA(IM)
 1112 CONTINUE
C
C  CALCULATE THERMAL CONDUCTANCES OF BODY COMPARTMENTS
C
      DO 1115 I=1,10
         N=4*I-3
         RADCM(N)=RADC(N)/2.0
         RADCM(N+1)=RADC(N)+(RADC(N+1)-RADC(N))/2.0
         RADCM(N+2)=RADC(N+1)+(RADC(N+2)-RADC(N+1))/2.0
         RADCM(N+3)=RADC(N+2)+(RADC(N+3)-RADC(N+2))/2.0
C
         CALL CONCYL(I,N,CN1,CN2,CN3,CN4)
C
         PI=3.6*2.0*3.1416*DEPTC(I)
         P=1.0/CN1*ALOG(RADC(N)/RADCM(N))
         Q=1.0/CN2*ALOG(RADCM(N+1)/RADC(N))
         R=1.0/CN2*ALOG(RADC(N+1)/RADCM(N+1))
         S=1.0/CN3*ALOG(RADCM(N+2)/RADC(N+1))
         V=1.0/CN3*ALOG(RADC(N+2)/RADCM(N+2))
         W=1.0/CN4*ALOG(RADCM(N+3)/RADC(N+2))
         FACTOR(N)=PI/(P+Q)*CONFAC
         FACTOR(N+1)=PI/(R+S)*CONFAC
         FACTOR(N+2)=PI/(V+W)*CONFAC
         FACTOR(N+3)=0.0
 1115 CONTINUE
      RETURN
      END
```

J.3 SUBROUTINE CONCYL

```
      SUBROUTINE CONCYL(I,N,CN1,CN2,CN3,CN4)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                  C
C SUBROUTINE CONCYL RECIEVES THE INTEGERS I AND N FROM SRT BODYSZ  C
C FOR A SPECIFIC BODY SEGMENT, THE CONDUCTIVITIES FOR EACH LAYER   C
C ARE CALCULATED AND RETURNED TO SRT BODYSZ.                   C
C                                                  C
C I REFERS TO THE BODY SEGMENT                                 C
C N IS I*4-3, THE CORE LAYER OF SEGMENT I                      C
C CN1 IS THE CONDUCTIVITY OF THE CORE                          C
C CN2 IS THE CONDUCTIVITY OF THE MUSCLE                        C
C CN3 IS THE CONDUCTIVITY OF THE FAT                           C
C CN4 IS THE CONDUCTIVITY OF THE SKIN                          C
C                                                  C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION RAD(40),DEPT(10),TCFACT(40),RADM(40)
      DATA RAD/5.21,5.52,5.79,6.0,7.16,10.65,11.64,11.84,
     $         3.11,4.92,5.29,5.48,3.11,4.92,5.29,5.48,
     $         3.95,6.21,6.59,6.79,3.95,6.21,6.59,6.79,
     $         0.87,0.99,1.17,1.38,0.87,0.99,1.17,1.38,
     $         0.98,1.06,1.26,1.45,0.98,1.06,1.26,1.45/
      DATA DEPT/33.67,87.74,35.27,35.27,67.35,67.35,52.16,52.16,
     $          68.06,68.06/
      DATA TCFACT/4.0,5.8,10.2,0.0,1.45,4.55,12.7,0.0,
     $            1.45,3.8,10.4,0.0,1.45,3.8,10.4,0.0,
     $            2.625,8.55,15.3,0.0,2.625,8.55,15.3,0.0,
     $            2.05,3.8,4.3,0.0,2.05,3.8,4.3,0.0,
     $            2.525,6.1,5.45,0.0,2.525,6.1,5.45,0.0/
      RADM(N)=RAD(N)/2.0
      RADM(N+1)=RAD(N)+(RAD(N+1)-RAD(N))/2.0
      RADM(N+2)=RAD(N+1)+(RAD(N+2)-RAD(N+1))/2.0
      RADM(N+3)=RAD(N+2)+(RAD(N+3)-RAD(N+2))/2.0
      PI=3.6*2.0*3.1416*DEPT(I)
      A=TCFACT(N+2)/PI
      B=ALOG(RAD(N+2)/RADM(N+2))+ALOG(RADM(N+3)/RAD(N+2))
      CN4=A*B
      CN3=CN4
      C=ALOG(RAD(N+1)/RADM(N+1))
      D=PI/TCFACT(N+1)
      E=1.0/CN3*ALOG(RADM(N+2)/RAD(N+1))
      CN2=C/(D-E)
      F=ALOG(RAD(N)/RADM(N))
      G=PI/TCFACT(N)
      H=1.0/CN2*ALOG(RADM(N+1)/RAD(N))
      CN1=F/(G-H)
      RETURN
      END
```

J.4 SUBROUTINE DISCON

```
      SUBROUTINE DISCON
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                               C
C SUBROUTINE DISCON STORES THE TIME POINTS OF THE CURVE STEP CHANGES IN    C
C ARRAY XHATAR SO THAT SUBROUTINE CRANE CAN STEP MORE ACCURATELY.          C
C                                                               C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C      PARAMETER NCRV=18,NCR=NCRV-1+10
C  UNIX 8/00, JVI
      PARAMETER (NCRV=18,NCR=NCRV-1+10)
      LOGICAL CRVL
C
      COMMON/XHATCK/CRVL(NCRV),ICRVP(NCRV),CRVS(50,NCR),XHATAR(50),JT
      COMMON/DWC/TIME
C
      I1=1
      DO 500 I=1,NCRV
      IF(.NOT. CRVL(I))GO TO 500
      IF(I .NE. 1)I1= I+9
      K=ICRVP(I)
C
C     DONT WANT TO SAVE AN XHAT EQUAL TO THE INITIAL TIME VALUE,SO START
C     WITH SECOND AND THIRD TIME STEP
C
  100 LX=5
      IF(K .LT. 3)GO TO 500
      DO 400 L=3,K
      IF(ABS(CRVS(LX,I1)-CRVS(LX-2,I1)) .GT. .1)GO TO 400
      IF(CRVS(LX,I1) .LT. TIME .OR. ABS(CRVS(LX,I1)-TIME) .LE. .1) GO
     $  TO 400
      IF(JT .EQ. 0)GO TO 300
      DO 200 M=1,JT
      IF(ABS(XHATAR(M)-CRVS(LX,I1)) .GT. .01   *ABS(XHATAR(M)))GO TO 200
      GO TO 400
  200 CONTINUE
  300 JT=JT+1
      IF(JT.GT.50)GO TO 550
      XHATAR(JT)=CRVS(LX,I1)
  400 LX=LX+2
      IF (I .NE. 1)GO TO 500
      I1=I1+1
      IF(I1 .GT. 10)GO TO 500
      GO TO 100
  500 CONTINUE
      GO TO 600
  550 WRITE (2,555)
  555 FORMAT(' THE NUMBER OF DISCONTINUOUS TIME POINTS IN THE CURVE ARRA
     *YS EXCEEDS 50. THE STEPPING PROCESS MAY NOT BE AS EXACT AFTER THES
     *E 50 POINTS')
      JT=50.
  600 CONTINUE
      RETURN
      END
```

J.5 SUBROUTINE ASCEND

```
      SUBROUTINE ASCEND(X,N)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                        C
C THIS SUBROUTINE SORTS (X) POINTS INTO A SEQUENCE OF ASCENDING X VALUES.  C
C N IS THE NO. OF POINTS IN THE SEQUENCE. THE ARRAY OCCUPIES THE SAME      C
C STORAGE AFTER STORING AS IT DID BEFORE.                        C
C                                                        C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      DIMENSION X(1)
C
C      DIMENSIONS OF ABOVE VARIABLES ARE ACTUALLY EFFECTED BY THE
C      HIGHER (CALLING) PROGRAM OR SUBROUTINE.
C
      EQUIVALENCE(I,T)
      J=1
C
C      J IS THE INDEX OF THE NEXT MEMBER OF THE SET OF POINTS WHICH WILL
C      BE ORDERED BY OPERATIONS IN THE INNER LOOP, DO 8 ON I.
C
      GO TO 3
C
C      THE ABOVE TRANSFER AVOIDS MIS-OPERATION IF N=1 OR LESS.
C      NORMALLY, PROGRESS TO STMT. 4.
C
    4 K=J
C
C      K IS THE TENTATIVE INDEX OF THE SMALLEST UN-ORDERED X VALUE.
C
      I=J+1
      GO TO 6
    5 I=I+1
    6 IF(X(I)-X(K))1,8,8
    1 K=I
    8 IF(I-N)5,7,7
C
C      K IS NO LONGER TENTATIVE.  IT IS INDEED THE INDEX OF SMALLEST X,
C      SO FAR UNORDERED.
C
    7 IF(K-J)2,9,2
    2 T=X(K)
      X(K)=X(J)
      X(J)=T
C
C     THE X'S HAVE BEEN SWAPPED, USING T AS TEMPORARY STORAGE
C
    9 J=J+1
    3 IF(J-N)4,10,10
   10 RETURN
      END
```

J.6 SUBROUTINE SUN

```
      SUBROUTINE SUN(TZ,LONG,LAT,WT,CN,ROG,CCM,IDAY,ITIME,M,N,AVRTOT)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                C
C SUBROUTINE SUN CAN BE USED TO CALCULATE THE INTENSITIES OF SOLAR RADIA-  C
C TION ON A SUBJECT WHO IS WORKING OR EXERCIZING OUTDOORS IN DAYLIGHT. BE- C
C CAUSE THIS CALCULATION IS DEPENDENT UPON TIME OF DAY, TIME OF YEAR AND   C
C SURFACE ORIENTATION, SUBROUTINES SUN1, SUN2, AND SUN3, RESPECTIVELY, ARE C
C CALLED BY SUN TO ACCOUNT FOR THESE EFFECTS.                              C
C                                                                C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION DEABC(5),RAYCOS(3)
      DIMENSION TRTOT(500)
      REAL LAT,LONG,LATR
C
      LATR=0.01745*LAT
      TANLAT=TAN(LATR)
      SL=SIN(LATR)
      CL=COS(LATR)
      J=1
      DO 1000 I=M,N
      WA=I
      AZIR=0.01745*WA
C
      CALL SUN1(IDAY,TANLAT,SUNRAS,DEABC)
C
      HANG=.2618*(ITIME-12.0+ TZ +DEABC(2))-0.01745*LONG
C
      CALL SUN2(HANG,DEABC,SL,CL,CN,RAYCOS,RDN,BS,CCM)
C
      IF(LATR.GE.0.0.AND.COS(HANG).GT.TAN(DEABC(1))/TAN(LATR).AND.
     $   RAYCOS(2).LT.0.0)RAYCOS(2)=-RAYCOS(2)
      IF(LATR.GE.0.0.AND.COS(HANG).LE.TAN(DEABC(1))/TAN(LATR).AND.
     $   RAYCOS(2).GT.0.0)RAYCOS(2)=-RAYCOS(2)
      IF (ABS(HANG).LT.ABS(SUNRAS)) GO TO 30
      RDN=0.0
       BS=0.0
       BG=0.0
   30 CONTINUE
      TILT=WT    *.01745
      GAMMA=COS(TILT)
C
      CALL SUN3(TILT,AZIR,RAYCOS,RDN,BS,ROG,GAMMA,ETA,RDIR,RDIF,RTOT,BG)
C
      RTOT=RTOT*CCM
      TRTOT(J)=RTOT
      J=J+1
 1000 CONTINUE
      IF(M.EQ.0)GO TO 1001
      TRTOT(361)=TRTOT(1)
      TTRTOT=0.0
      DO 1003 K=1,359,2
      TTRTOT=1.0*(TRTOT(K)+4.0*TRTOT(K+1)+TRTOT(K+2))+TTRTOT
 1003 CONTINUE
      AVRTOT=TTRTOT/3.0/360.0
      GO TO 1002
 1001 CONTINUE
```

```
      AVRTOT=TRTOT(1)
 1002 CONTINUE
      RETURN
      END
```

J.7 SUBROUTINE SUN1

```
      SUBROUTINE SUN1(IDOY,TL,SUNRAS,DEABC)
      DIMENSION DEABC(5)
      C1=COS(.01721*IDOY)
      S1=SIN(.01721*IDOY)
      S2=2.*S1*C1
      C2=C1*C1-S1*S1
      C3=C1*C2-S1*S2
      S3=C1*S2+S1*C2
      DEABC(1)=.00527-.4001*C1-.003996*C2-.004240*C3+.0672*S1
      DEABC(2)=.696E-4+.706E-2*C1-.0533*C2-.157E-2*C3-.122*S1-.156*S2
     *-.556E-2*S3
      DEABC(3)=368.44+24.52*C1-1.14*C2-1.09*C3+.58*S1-.18*S2+.28*S3
      DEABC(4)=.1717-.0344*C1+.0032*C2+.0024*C3-.0043*S1-.0008*S3
      DEABC(5)=.0905-.0410*C1+.0073*C2+.0015*C3-.0034*S1+.0004*S2
     *-.0006*S3
      SUNRAS=ACOS(-TL*DEABC(1))
      RETURN
      END
```

J.8 SUBROUTINE SUN2

```
      SUBROUTINE SUN2(H,DEABC,SL,CL,CN,RAYCOS,RDN,BS,CCM)
      DIMENSION DEABC(5),RAYCOS(3)
      DQ=DEABC(1)*DEABC(1)
      SD=DEABC(1)*(1.-.16667*DQ)
      CD=1.0-0.5*DQ
      SH=SIN(H)
      CH=COS(H)
      RAYCOS(3)=SL*SD+CL*CH*CD
      RAYCOS(1)=CD*SH
      RAYCOS(2)=(1.0-(RAYCOS(3))**2-(RAYCOS(1))**2)**0.5
      IF (RAYCOS(3).GT.0.001) GO TO 20
   10 RAYCOS(3)=0.0
      RDN=0.
      BS=0.
      RETURN
   20 RDN=DEABC(3)*CN*EXP(-DEABC(4)/RAYCOS(3))*CCM
      BS=DEABC(5)*RDN/(CN*CN)
      RETURN
      END
```

J.9 SUBROUTINE SUN3

```
      SUBROUTINE SUN3(WT,WA,RAYCOS,RDN,BS,ROG,GAMMA,ETA,RDIR,RDIF,RTOT,
     *BG)
      DIMENSION RAYCOS(3)
      BG=ROG*(BS+RDN*RAYCOS(3))
      IF (ABS(WT-0.0)-.002) 10,10,20
   10 GAMMA=1.0
      ETA=RAYCOS(3)
      GO TO 150
   20 IF (ABS(WT-1.5708)-.002) 30,30,40
   30 GAMMA=0.0
      SWT=1.0
      GO TO 50
   40 GAMMA=COS(WT)
      SWT=SIN(WT)
   50 IF (ABS(WA-0.0)-.002) 100,100,60
   60 IF (ABS(WA-1.5708)-.002) 110,110,70
   70 IF (ABS(WA-3.1416)-.002) 120,120,80
   80 IF (ABS(WA-4.7114)-.002) 130,130,90
   90 SWA=SIN(WA)
      CWA=COS(WA)
      GO TO 140
  100 SWA=0.0
      CWA=1.0
      GO TO 140
  110 SWA=1.0
      CWA=0.0
      GO TO 140
  120 SWA=0.0
      CWA=-1.0
      GO TO 140
  130 SWA=-1.0
      CWA=0.0
  140 ETA=(RAYCOS(1)*SWA+RAYCOS(2)*CWA)*SWT+RAYCOS(3)*GAMMA
  150 IF (ETA) 160,160,170
  160 RDIR=0.0
      GO TO 180
  170 RDIR=RDN*ETA
  180 IF (WT.GT.0.7854) GO TO 190
      RDIF=BS
      GO TO 240
  190 IF (WT.GT.2.35619) GO TO 220
      IF (ETA+0.2) 200,210,210
  200 Y=0.45
      GO TO 230
  210 Y=0.55+0.437*ETA+0.313*ETA*ETA
      GO TO 230
  220 RDIF=BG
      GO TO 240
  230 RDIF=Y*BS+0.5*BG
  240 RTOT=RDIR+RDIF
      RETURN
      END
```

J.10 SUBROUTINE LAGIN

```
      SUBROUTINE LAGIN(ICODE,T,NN,KK,XX,Y)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                        C
C SUBROUTINE LAGIN USES THE LAGRANGIAN INTERPOLATION TECHNIQUE TO RETURN   C
C THE VALUE OF A DEPENDENT VARIABLE FOR A GIVEN INDEPENDENT VARIABLE FROM  C
C A SET OF POINT PAIRS REPRESENTING A CURVE OF THE VARIABLES.              C
C                                                        C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     ICODE =CODE NUMBER FOR CALL. OF NO USE IN SUBROUTINE
C     T     =ARRAY NAME. INPUT THE CURVE WITH THE INDEPENDENT VARIABLE AND
C     DEPENDENT VARIABLE ALTERNATING WITH THE INDEPENDENT VARIABLE FIRST
C     NN    =NUMBER OF POINT PAIRS ON CURVE.
C    KK=NUMBER OF POINTS TO BE USED IN INTERPOLATION=
C     XX    =INDEPENDENT VARIABLE
C     Y     =DEPENDENT VARIABLE  (ANSWER) TO BE RETURNED TO CALLING PROGRAM
C
      DIMENSION T(*)
      XNOUSE = ICODE
   50 N=NN
      K=KK
      X=XX
  100 IF(X-T(1)) 200,300,300
  200 L=1
      GO TO 500
  300 N2=N+N
      IF(X-T(N2-1))600,600,400
  400 L=N2-3
  500 CONTINUE
      K=2
      GO TO 1600
  600 I=3
  700 IF(X-T(I))1000,800,900
  800 SUM=T(I+1)
      GO TO 2600
  900 I=I+2
      GO TO 700
 1000 K2=K/2
      M=K2+K2
      L=I-M
 1005 IF(M-K)1010,1100,1010
 1010 IF(X+X-T(I)-T(I-2))1020,1100,1100
 1020 L=L-2
 1100 IF(L-1)1200,1300,1300
 1200 L=1
      GO TO 1600
 1300 M=2*(N-K)+1
 1400 IF(L-M)1600,1600,1500
 1500 L=M
 1600 M=L+K+K-2
 1700 SUM=0.
 1800 DO 2500 I=L,M,2
 1900 P=1.
 2000 DO 2300 J=L,M,2
 2100 IF(I-J)2200,2300,2200
 2200 P=P*(X-T(J))/(T(I)-T(J))
```

```
2300 CONTINUE
2400 SUM=SUM+P*T(I+1)
2500 CONTINUE
2600 Y=SUM
     RETURN
     END
```

J.11 SUBROUTINE SUIT

```
      SUBROUTINE SUIT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                   C
C SUBROUTINE SUIT PROVIDES A MATH MODEL DESCRIBING THE HEAT AND    C
C MASS EXCHANGE BETWEEN THE CREWMAN'S BODY OR UNDERGARMENT AND THE C
C GAS CIRCULATING THROUGH THE SUIT, THE HEAT EXCHANGE BETWEEN THE  C
C CREWMAN OR UNDERGARMENT AND THE SUIT, THE HEAT EXCHANGE BETWEEN  C
C THE SUIT GAS AND THE SUIT, THE HEAT LEAK THROUGH THE SUIT, AND   C
C THE HEAT EXCHANGE BETWEEN THE SUIT AND SURROUNDING ENVIRONMENTS. C
C THE HEAT EXCHANGE OF THE LCG WITH ITS SURROUNDINGS IS ALSO       C
C PROVIDED FOR.                                           C
C                                                   C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      PARAMETER (MM=71,M2=MM+2)
      PARAMETER (NCRV=18)
      LOGICAL STEPF,CMODE,INIT,IPURGE,CURVES
      DOUBLE PRECISION QVECTS
C
C  T(42-51)-TEMPS  INSIDE THE SUIT, T(52-61)- TEMPS OUTSIDE THE SUIT
C
      DIMENSION TIS(10),TOS(10)
      DIMENSION PCA(10),ACSUTE(10),ARSUTE(10),ARE(10),SUITA(10),
     $          QEMIT(10),WGE(10),TGINE(10),FC(10),FR(10),QUGG(10),
     $          QUGIS(10),QW(10),QUG(10),QISG(10),QG(10),QOSW(10),
     $          QOSA(10),PH2OO(10),PH2OI(10),CMT(10)
      DIMENSION COEF1(10),COEF2(10),COEF3(10), BF(40),
     $          XCOEF1(10),XCOEF2(10),XCOEF3(10)
C
      EQUIVALENCE(T(42),TIS(1)),(T(52),TOS(1))
      EQUIVALENCE (CMODE,CRVL(2))
C
      COMMON/METCOM/ MODE,ICOND,INIT,IPURGE,II(10),CURVES,RM,UEFF,AC,AR,
     &       TCAB,TW,VCAB,PCAB,ALUG,AKUG,EUG,WF,TWI,CPW,UAG,
     &       DTIME,TDEWC,TDEW,U,ACSUIT(10),ARSUIT(10),CPG,CFMS,
     &       TGIN,PG,PO2,ALS(10),AKS(10),EIS(10),EOS(10),CPS(10),
     &       QASRB(10),VF,VEFF,WORK,TUGAV,WS(10),C(41),TWO,SQUG,
     &       QEVAP,TOTL,QSHIV,QSTOR,STORAT,SCAB1,CLO,TISAV,WG,
     &       TOSAV,TGOUTS,RMIX,PN2,QLCG(40),QSEN(40),QRAD(40),
     &       TSET(43),EMAX(40),PCFLO(5),G,TUG(10),TGOUT(10),TG(10),
     &       TM(10),WH2OO,WO2OUT,WCO2O,WGOUT,SHSO,PULSE,QR,IPLOP,
     &       TDEWA,SCABC,QRSEN1,QRSEN5,ACE(10),SQUGW,QLAT(40),
     &       WGIN,VOLHMT,HCO2MH,QRSEN2,QRSEN3,QRSEN6,WH2OIN,QRSE15,QD
      COMMON/TMAT/QVECTS(MM),QVECT(MM),TDIFF,QVECST,
     $       PREC,DONT,HELP,OLDT,H,ENDONX,XHAT,OKPC,TRAN,WGE10,
     $       NCO2,T(M2),NMT,IQ,ICYCLE,IFLG,NB(MM),MINUT,INITL
      COMMON/DERSUT/  QUGIS,QISG,ACSUTE,QOSW,QOSA,SUITA,SQOSA,SQOSW,
     $  QUGG
      COMMON/LCG/ WDOT1,UASB,EL,EL2,DE,WT,CPHX,WTDUCT,CPDUCT,WTDUC2,
     $  ELP,ELP2,DEP,RHOC,WTPIPE,WTPIP2,CPP,SUBKA,UAHXS,WN2
      COMMON/PRESS/PH2OO,PH2OI,PH2OOO(10)
      COMMON/DIAG/PTIM
      COMMON/SWEAT/SWEAT,QDIF(40)
      COMMON/QTSUIT/QTSUIT
      COMMON/DAVE/PH2O10
      COMMON/GFC/SUBIN,SUBOUT,PH2OSO,MODEO
```

```
      COMMON/DWC/TIME
      COMMON/CHGTGI/TAVD,TAVD2,TAVP,TAVP2
      COMMON/TEST/STEPF
      COMMON/XHATCK/CRVL(NCRV)
      COMMON/HUM/WTMXD
      COMMON/EMAX/EMAXM(40)
      COMMON/BLUD/TBF,TSBF,BF,SROR
      COMMON/SKIN/TAVSKN,O2RATE,CO2RAT
      COMMON/BSIZE/BRM
      COMMON/RATCO/RCOEF1(10),RCOEF2(10),RCOEF3(10)
      COMMON/UAGNEW/CCUAG(26),NPUAG
C
C
C      DATA(II(I),I=1,10)/8,12,16,20,24,28,32,36,40,4/
      DATA(PCA(I),I=1,10)/0.3602,0.06705,0.06705,0.1587,0.1587,0.025,
     $                    0.025,0.0343,0.0343,0.07/
      DATA(XCOEF1(I),I=1,10)/1.21,1.24,1.24,1.1,1.1,1.31,1.31,1.2,1.2,
     $                      2.04/
      DATA(XCOEF2(I),I=1,10)/0.918,1.35,1.35,1.25,1.25,1.77,1.77,1.75,
     $                      1.75,1.06/
      DATA(XCOEF3(I),I=1,10)/1.15,1.17,1.17,1.07,1.07,1.22,1.22,1.14,
     $                      1.14,1.71/
      DATA WO2IN,WCO2IN,WFO,WFI,EMAX1/0.,0.,0.,0.,0./
      SAVE
C
C   J SUBSCRIPTS IN THIS SUBROUTINE 1=TRUNK 2=RIGHT ARM 3=LEFT ARM
C                 4=RIGHT LEG 5=LEFT LEG 6=RIGHT HAND 7=LEFT HAND
C                 8=RIGHT FOOT 9=LEFT FOOT 10=HEAD
C
C     FPH2OO(FPH2OI,FTUG,FCMT,FACE,FTG,FWGE)=FPH2OI+(VPP(FTUG)-FPH2OI)*
C    $(1.-EXP(-FCMT*PG*FACE*144./(RMIX*(FTG+460.)*FWGE)))
C
      II = ( /8,12,16,20,24,28,32,36,40,4/ )
C IF INPUT IS BY CURVES, THEN SKIP QDIF ASSIGNMENTS
C
      IF(CURVES) GO TO 110
C
C IF THIS IS THE NOT THE INITIAL CALL OF SRT SUIT, THEN SKIP INTERNAL
C VARIABLE CALCULATIONS
C
      IF (.NOT. INIT) GO TO 100
C
C IF IMPOSED CONDITIONS, THEN SKIP QDIF ASSIGNMENTS
C
      IF(ICOND.GT. 1) GO TO 110
      QDIF(4) = 1.984
      QDIF(8) = 9.92
      QDIF(12) = 3.1744
      QDIF(16) = 3.1744
      QDIF(28) = 0.7936
      QDIF(32) = 0.7936
      QDIF(20) = 6.944
      QDIF(24) = 6.944
      QDIF(36) = 1.1904
      QDIF(40) = 1.1904
  110 U=UEFF/100.0*(RM-BRM)
      WORK=RM-BRM-U
      PN2=PG-PO2
```

```
      RMIX=1545./(PO2/PG*32.+PN2/PG*28.)
      WO2IN=60.*CFMS*PO2*144./(48.3*(TGIN+460.))
      WN2  =60.*CFMS*PN2*144./(55.2*(TGIN+460.))
      WCO2IN=0.
      WGIN=WO2IN+WN2+WCO2IN
      WOLH=VPP(TDEW)/PG*18.016/(PO2/PG*32.+PN2/PG*28.)
      WH2OIN=WGIN*WOLH
      WGIN=WGIN+WH2OIN
      DO 99 I=1,10
      SUITA(I)=ALS(I)/AKS(I)
   99 CONTINUE
      IF(MODE .EQ. 3) SUITA(10)=0.
      IF (.NOT. INIT) GO TO 100
      DO 101 I=1,10
      ACE(I)=PCA(I)*AC
      ARE(I)=PCA(I)*AR
      ARSUTE(I)=ARSUIT(I)
      ACSUTE(I)=ACSUIT(I)
      COEF1(I)=XCOEF1(I)*RCOEF1(I)
      COEF2(I)=XCOEF2(I)*RCOEF2(I)
      COEF3(I)=XCOEF3(I)*RCOEF3(I)
  101 CONTINUE
C
      IF(ICOND.GT.0.AND.MODEO.NE.0.AND.(STEPF.OR.CMODE.OR.CURVES))
     $         GO TO 103
      WH2OO=WH2OIN+.3
      WO2OUT=WO2IN-O2RATE
      WCO2O=WCO2IN+CO2RAT
      WGOUT=WH2OO+WO2OUT+WCO2O+WN2
      WFO=0.67
      WFI=1.-WFO
      DO 102 I=1,10
      J=II(I)
      TOS(I)=TCAB
      TIS(I)=T(8)
      TGOUT(I)=T(J)-3.
      TG(I)=TCAB
      TM(I)=(TUG(I)+TIS(I))/2.
      IF(ICOND .GT. 0) GO TO 102
      TUG(I)=T(J)
  102 CONTINUE
  103 CONTINUE
      INIT=.FALSE.
C
C  THE PRECEDING STATEMENTS WILL BE EXECUTED ONLY ON THE INITIAL CALL OF
C  SUBROUTINE SUIT FOR ANY GIVEN SET OF CONDITIONS
C
  100 WG=WFO*WGOUT+WFI*WGIN
      IF(CFMS.LE.0.0)WG=0.0
      WH2O=WFO*WH2OO+WFI*WH2OIN
      WO2=WFO*WO2OUT+WFI*WO2IN
      WCO2=WFO*WCO2O+WFI*WCO2IN
      IF(TDEW.GE.TGIN)TDEW=TGIN
      WGD1 =WO2OUT+WCO2O+WN2
      WTMXD=(WO2OUT*32.0+WCO2O*44.0+WN2*28.0)/WGD1
      IF(MODE.EQ.3)WGD1=WGD1-WCO2O
      IF(MODE.EQ.3)WTMXD=(WO2OUT*32.0+WN2*28.0)/WGD1
      DUMMI=WTMXD   /(18.0*1040.0)
```

```
      IF (MODE-2)132,130,131
C
C CALCULATE MASS FLOW RATE AND TEMPERATURE OF THE GAS INTO
C EACH SUIT SEGMENT FOR MODES 1, 2, OR 3.
C
C  MODE=1 NORMAL SUITED MODE
C
  132 WGE(1)=1.0*WG
      WGE(2)=0.1*WG
      WGE(3)=0.1*WG
      WGE(4)=0.1*WG
      WGE(5)=0.1*WG
      WGE(6)=0.1*WG
      WGE(7)=0.1*WG
      WGE(8)=0.1*WG
      WGE(9)=0.1*WG
      WGE(10)=0.2*WG
      WGD2 =0.1*WGD1
      WGD3 =0.1*WGD1
      WGD4 =0.1*WGD1
      WGD5 =0.1*WGD1
      WGD6 =0.1*WGD1
      WGD7 =0.1*WGD1
      WGD8 =0.1*WGD1
      WGD9 =0.1*WGD1
      WGD10=0.2*WGD1
      TGINE(1)=0.4*TGIN+0.1*TGOUT(2)+0.1*TGOUT(3)+0.1*TGOUT(4)
     $                            +0.1*TGOUT(5)+0.2*TGOUT(10)
      TGINE(2)=TGOUT(6)
      TGINE(3)=TGOUT(7)
      TGINE(4)=TGOUT(8)
      TGINE(5)=TGOUT(9)
      TGINE(6)=TGIN
      TGINE(7)=TGIN
      TGINE(8)=TGIN
      TGINE(9)=TGIN
      TGINE(10)=TGIN
      GO TO 140
C
C  MODE= 2 EVA MODE
C
  130 WGE(1)=WG
      WGE(2)=0.375*WG
      WGE(3)=0.375*WG
      WGE(4)=0.125*WG
      WGE(5)=0.125*WG
      WGE(10)=WG
      WGE10=WGE(10)
      WGE(6)=0.375*WG
      WGE(7)=0.375*WG
      WGE(8)=0.125*WG
      WGE(9)=0.125*WG
      WGD2 =0.375*WGD1
      WGD3 =0.375*WGD1
      WGD4 =0.125*WGD1
      WGD5 =0.125*WGD1
      WGD10=WGD1
      WGD6 =0.375*WGD1
```

```
      WGD7 =0.375*WGD1
      WGD8 =0.125*WGD1
      WGD9 =0.125*WGD1
      TGINE(1)=TGOUT(10)
      TGINE(2)=TGOUT(1)
      TGINE(3)=TGOUT(1)
      TGINE(4)=TGOUT(1)
      TGINE(5)=TGOUT(1)
      TGINE(10)=TGIN
      TGINE(6)=TGOUT(2)
      TGINE(7)=TGOUT(3)
      TGINE(8)=TGOUT(4)
      TGINE(9)=TGOUT(5)
      GO TO 140
C
C  MODE=3 HELMET-OFF SUITED MODE
C
  131 WGE(6)=0.3*WG
      WGE(7)=0.3*WG
      WGE(8)=0.2*WG
      WGE(9)=0.2*WG
      WGE(2)=WGE(6)
      WGE(3)=WGE(7)
      WGE(4)=WGE(8)
      WGE(5)=WGE(9)
      WGE(1)=WG
      WGE(10)=0.0
      WGE10=WGE(10)
      WGD6 =0.3*WGD1
      WGD7 =0.3*WGD1
      WGD8 =0.2*WGD1
      WGD9 =0.2*WGD1
      WGD2 =WGD6
      WGD3 =WGD7
      WGD4 =WGD8
      WGD5 =WGD9
      WGD10=0.0
      TGINE(6)=TGIN
      TGINE(7)=TGIN
      TGINE(8)=TGIN
      TGINE(9)=TGIN
      TGINE(2)=TGOUT(6)
      TGINE(3)=TGOUT(7)
      TGINE(4)=TGOUT(8)
      TGINE(5)=TGOUT(9)
      TGINE(1)=0.3*TGOUT(2)+0.3*TGOUT(3)+0.2*TGOUT(4)+0.2*TGOUT(5)
      TGINE(10)=0.0
C
  140 CONTINUE
      DO 3000 I=1,10
      QW(I) = 0.0
 3000 CONTINUE
      TOLAT=TOTL + SROR
      TAVSKN=0.446*T(8)+0.0826*T(12)+0.0826*T(16)+0.1945*T(20)+0.1945*
     $             T(24)
      IF (WF .GT. 0) THEN
         CALL LAGIN(1,CCUAG,NPUAG,2,TOLAT,UAG)
C         UAG=UAG*(1.0-1.08*EXP(-0.0166*WF))
```

```
         IF(UAG.LT.0.0) UAG=0.0
         DTLCG=(1.0-(EXP(-UAG/(WF*CPW))))*(TAVSKN-TWI)
      ELSE
         UAG = 0.
         DTLCG = 0.
      ENDIF
      DO 3001 I=1,5
      QW(I)=PCFLO(I)*WF*CPW*DTLCG
 3001 CONTINUE
      TWO = TWI + DTLCG
      DO 104 I=1,10
C
C  FOR HELMET OFF MODE HEAD SKIN SEES CABIN NOT SUIT
C
      IF(MODE.EQ.3.AND.I.EQ.10)GO TO 1000
C
      J=II(I)
      FC(I)=0.134*WGE(I)**(1./3)*ACE(I)*COEF1(I)
      FR(I)=0.1713E-8*ACE(I)*EUG*EIS(I)/(EIS(I)+EUG-EUG*EIS(I))
C
   17 TGOLD=TG(I)
      QRSEN1=0.5*0.0418*PG*144.0/(48.3*(TG(10)+459.69))*RM*((0.385*T(1)
     $+0.086*T(2)+0.0287*T(3)+0.238*T(5)+0.2615*T(6))-TG(10))*CPG
      IF(MODE.EQ.3)QRSEN1=0.5*0.0418*PCAB*144.0/(48.3*(TCAB+459.69))*RM*
     $((0.385*T(1)+0.086*T(2)+0.0287*T(3)+0.238*T(5)+0.2615*T(6))-TCAB)
     $*CPG
      QRSEN2 = 0.172 * QRSEN1
      QRSEN3 = 0.0574 * QRSEN1
      QRSEN6 = 0.523 * QRSEN1
      QRSEN5 = 0.476 * QRSEN1
      QRSEN1=0.771*QRSEN1
      QRSE15=QRSEN1+QRSEN5+QRSEN3+QRSEN2+QRSEN6
C
      TG(I)=TM(I)-(TM(I)-TGINE(I))*WGE(I)*CPG/(2.*FC(I))*(1.-EXP(-2.*FC(
     $I)/(WGE(I)*CPG)))
      IF(I.EQ.10) TG(10) = TG(10) + (QRSEN1 + QRSEN5 + QRSEN2 + QRSEN3 +
     $QRSEN6)/(WGE(10)*CPG)
   10 TUGOLD=TUG(I)
      QUGG(I)=FC(I)*(TUG(I)-TG(I))
      QUGIS(I)=FR(I)*((TUG(I)+460.)**4-(TIS(I)+460.)**4)
      QUG(I)=QUGG(I)+QUGIS(I)+QW(I)
      IF(I.GT.5)GO TO 23
      TUG(I)=T(J)-CLO/ACE(I)*(QUGG(I)+QUGIS(I))
      TUG(I)=0.5*(TUG(I)+TUGOLD)
      IF(ABS(TUG(I)-TUGOLD)/TUG(I)-1.E-4)15,15,10
C
C  HEAD, HANDS, FEET ARE NOT COVERED BY UNDERGARMENT. FOR CONVENIENCE IN
C  COMPUTATION TSKIN OF EACH OF THESE ELEMENTS IS CALLED TUG
C
   23 TUG(I)=T(J)
C
   15 TM(I)=(TUG(I)+TIS(I))/2.
      TGOUT(I)=TM(I)-(TM(I)-TGINE(I))*EXP(-2.*FC(I)/(WGE(I)*CPG))
      IF(I .EQ. 10) TGOUT(10)=TGOUT(10)+QRSE15/(WGE(10)*CPG)
      IF(ABS(TG(I)-TGOLD)-.05)11,11,16
   16 IF(I.NE.10)TG(I)=0.9*TG(I)+0.1*TGOLD
      IF(I.EQ.10)TG(10)=0.5*TG(10)+0.5*TGOLD
      GO TO 17
```

```
C
   11 QISG(I) = FC(I)*(TIS(I)-TG(I)) * ACSUTE(I)/ACE(I)
      QG(I)=QUGG(I)+QISG(I)
C
      IF (QASRB(I))20,20,21
C
C  QOSW FOR IN THE CABIN CASE
C
   20 QOSW(I)=0.1713E-8*ARSUTE(I)*VF*EOS(I)*((TOS(I)+460.)**4-(TW+460.)*
     $*4)
      GO TO 22
C
C  QOSW FOR LUNAR SURFACE CASE
C
   21 QEMIT(I)=0.1713E-8*ARSUTE(I)*EOS(I)*(TOS(I)+460.)**4
      QOSW(I)=QEMIT(I)-QASRB(I)*ARSUTE(I)
C
C  FREE AND FORCE CONVECTION WITH OUTER SUIT
C
   22 QOSA(I)=0.0212*SQRT(PCAB*VCAB)*ACSUTE(I)*(TOS(I)-TCAB)
     $          *COEF2(I)
      QOSA1=0.06*ACSUTE(I)*(PCAB**2*G*ABS(TOS(I)-TCAB))**0.25*COEF3(I)*
     $      (TOS(I)-TCAB)
      IF ( ABS(QOSA1) .GT. ABS(QOSA(I)) ) QOSA(I) = QOSA1
C
      IF(MODE.EQ.1) TGOUTS=TGOUT(1)
      IF(MODE.EQ.2)TGOUTS=0.375*TGOUT(6)+0.375*TGOUT(7)+0.125*TGOUT(8)+
     $                 0.125*TGOUT(9)
      CMT(I)=0.00817*WGE(I)**(1./3.)*(TG(I)+460.0)**1.54/PG
     $          *COEF1(I)
      GO TO 104
 1000 TG(10)=0.0
      TUG(10)=T(4)
      TM(10)=0.0
      TGOUT(10)=0.0
      QISG(10)=0.0
      QG(10)=0.0
      QUGIS(10)=0.1713E-8*ARE(10)*EUG*((T(4)+459.69)**4-(TW+459.69)**4)
      QUGG(10)=0.0212*SQRT(PCAB*VCAB)*ACE(10)*(T(4)-TCAB)
     $          *1.22
      QUGG1=0.06*ACE(10)*(PCAB**2*G*ABS(T(4)-TCAB))**0.25*1.71
     $           *(T(4)-TCAB)
      IF(QUGG1.GT.QUGG(10))QUGG(10)=QUGG1
      QUG(10)=QUGG(10)+QUGIS(10)
      TGOUTS=TGOUT(1)
  104 CONTINUE
      IF (MODE .EQ. 3) GO TO 1001
      IF(MODE.EQ.2)GO TO 4000
      PH2OI(6)=VPP(TDEW)
      IF(IPURGE)PH2OI(6)=0.0
      PH2OI(7)=PH2OI(6)
      PH2OI(8)=PH2OI(6)
      PH2OI(9)=PH2OI(6)
      PH2OI(10)=PH2OI(6)
      PH2OO(6)=FPH2OO(PH2OI(6),TUG(6),CMT(6),ACE(6),TG(6),WGE(6))
      PH2OO(7)=FPH2OO(PH2OI(7),TUG(7),CMT(7),ACE(7),TG(7),WGE(7))
      PH2OO(8)=FPH2OO(PH2OI(8),TUG(8),CMT(8),ACE(8),TG(8),WGE(8))
      PH2OO(9)=FPH2OO(PH2OI(9),TUG(9),CMT(9),ACE(9),TG(9),WGE(9))
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```
      DUMMY=QLAT(28)*DUMMI/WGD6
      PH2O6 =PH2OI( 6)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(32)*DUMMI/WGD7
      PH2O7 =PH2OI( 7)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(36)*DUMMI/WGD8
      PH2O8 =PH2OI( 8)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(40)*DUMMI/WGD9
      PH2O9 =PH2OI( 9)+DUMMY*PG/(DUMMY+1.0)
      PH2OI(2)=AMIN1(PH2O6,PH2OO(6))
      PH2OI(3)=AMIN1(PH2O7,PH2OO(7))
      PH2OI(4)=AMIN1(PH2O8,PH2OO(8))
      PH2OI(5)=AMIN1(PH2O9,PH2OO(9))
      PH2OOO(6)=PH2OI(2)
      PH2OOO(7)=PH2OI(3)
      PH2OOO(8)=PH2OI(4)
      PH2OOO(9)=PH2OI(5)
      PH2OO(2)=FPH2OO(PH2OI(2),TUG(2),CMT(2),ACE(2),TG(2),WGE(2))
      PH2OO(3)=FPH2OO(PH2OI(3),TUG(3),CMT(3),ACE(3),TG(3),WGE(3))
      PH2OO(4)=FPH2OO(PH2OI(4),TUG(4),CMT(4),ACE(4),TG(4),WGE(4))
      PH2OO(5)=FPH2OO(PH2OI(5),TUG(5),CMT(5),ACE(5),TG(5),WGE(5))
      DUMMY=QLAT(12)*DUMMI/WGD2
      PH2O2 =PH2OI( 2)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(16)*DUMMI/WGD3
      PH2O3 =PH2OI( 3)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(20)*DUMMI/WGD4
      PH2O4 =PH2OI( 4)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(24)*DUMMI/WGD5
      PH2O5 =PH2OI( 5)+DUMMY*PG/(DUMMY+1.0)
      PH2OOO(2)=AMIN1(PH2O2,PH2OO(2))
      PH2OOO(3)=AMIN1(PH2O3,PH2OO(3))
      PH2OOO(4)=AMIN1(PH2O4,PH2OO(4))
      PH2OOO(5)=AMIN1(PH2O5,PH2OO(5))
      PH2OO(10)=FPH2OO(PH2OI(10),TUG(10),CMT(10),ACE(10),TG(10),WGE(10))
     $         +QR*DUMMI/WGD10*PG/(1.0+QR*DUMMI*WGD10)
      DUMMY=(QLAT(4)+QR)*DUMMI/WGD10
      PH2O10=PH2OI(10)+DUMMY*PG/(DUMMY+1.0)
       PH2OOO(10)=AMIN1(PH2OO(10),PH2O10)
      PH2OI(1)=0.2*PH2OOO(10)+0.1*PH2OOO(2)+0.1*PH2OOO(3)+0.1*PH2OOO(4)
     $         +0.1*PH2OOO(5)+0.4*PH2OI(6)
      PH2OO(1)=FPH2OO(PH2OI(1),TUG(1),CMT(1),ACE(1),TG(1),WGE(1))
      DUMMY=QLAT( 8)*DUMMI/WGD1
      PH2O1 =PH2OI( 1)+DUMMY*PG/(DUMMY+1.0)
      PH2OOO(1)=AMIN1(PH2O1,PH2OO(1))
      PH2OSO=PH2OOO(1)
      GO TO 1002
 4000 CONTINUE
      PH2OI(10)=VPP(TDEW)
      IF(IPURGE)PH2OI(10)=0.0
      PH2OO(10)=FPH2OO(PH2OI(10),TUG(10),CMT(10),ACE(10),TG(10),WGE(10))
     $         +QR*DUMMI/WGD10*PG/(1.0+QR*DUMMI*WGD10)
      DUMMY=(QLAT(4)+QR)*DUMMI/WGD10
      PH2O10=PH2OI(10)+DUMMY*PG/(DUMMY+1.0)
      PH2OI(1)=AMIN1(PH2OO(10),PH2O10)
      PH2OO(1)=FPH2OO(PH2OI(1),TUG(1),CMT(1),ACE(1),TG(1),WGE(1))
      DUMMY=QLAT( 8)*DUMMI/WGD1
      PH2O1 =PH2OI( 1)+DUMMY*PG/(DUMMY+1.0)
      PH2OI(2)=AMIN1(PH2OO(1),PH2O1)
      PH2OOO(1) = PH2OI(2)
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      PH2OO(2)=FPH2OO(PH2OI(2),TUG(2),CMT(2),ACE(2),TG(2),WGE(2))
      DUMMY=QLAT(12)*DUMMI/WGD2
      PH2O2 =PH2OI( 2)+DUMMY*PG/(DUMMY+1.0)
      PH2OI(3)=PH2OI(2)
      PH2OO(3)=FPH2OO(PH2OI(3),TUG(3),CMT(3),ACE(3),TG(3),WGE(3))
      DUMMY=QLAT(16)*DUMMI/WGD3
      PH2O3 =PH2OI( 3)+DUMMY*PG/(DUMMY+1.0)
      PH2OI(6)=AMIN1(PH2OO(2),PH2O2)
      PH2OI(7)=AMIN1(PH2OO(3),PH2O3)
      PH2OOO(2)=PH2OI(6)
      PH2OOO(3)=PH2OI(7)
      PH2OO(6)=FPH2OO(PH2OI(6),TUG(6),CMT(6),ACE(6),TG(6),WGE(6))
      PH2OO(7)=FPH2OO(PH2OI(7),TUG(7),CMT(7),ACE(7),TG(7),WGE(7))
      PH2OI(4)=PH2OI(2)
      PH2OI(5)=PH2OI(2)
      PH2OO(4)=FPH2OO(PH2OI(4),TUG(4),CMT(4),ACE(4),TG(4),WGE(4))
      PH2OO(5)=FPH2OO(PH2OI(5),TUG(5),CMT(5),ACE(5),TG(5),WGE(5))
      DUMMY=QLAT(20)*DUMMI/WGD4
      PH2O4 =PH2OI( 4)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(24)*DUMMI/WGD5
      PH2O5 =PH2OI( 5)+DUMMY*PG/(DUMMY+1.0)
      PH2OI(8)=AMIN1(PH2O4,PH2OO(4))
      PH2OI(9)=AMIN1(PH2O5,PH2OO(5))
      PH2OOO(4)=PH2OI(8)
      PH2OOO(5)=PH2OI(9)
      PH2OO(8)=FPH2OO(PH2OI(8),TUG(8),CMT(8),ACE(8),TG(8),WGE(8))
      PH2OO(9)=FPH2OO(PH2OI(9),TUG(9),CMT(9),ACE(9),TG(9),WGE(9))
      DUMMY=QLAT(28)*DUMMI/WGD6
      PH2O6 =PH2OI( 6)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(32)*DUMMI/WGD7
      PH2O7 =PH2OI( 7)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(36)*DUMMI/WGD8
      PH2O8 =PH2OI( 8)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(40)*DUMMI/WGD9
      PH2O9 =PH2OI( 9)+DUMMY*PG/(DUMMY+1.0)
      PH2OOO(10)=AMIN1(PH2OO(10),PH2O10)
      PH2OOO(6)=AMIN1(PH2OO(6),PH2O6)
      PH2OOO(7)=AMIN1(PH2OO(7),PH2O7)
      PH2OOO(8)=AMIN1(PH2OO(8),PH2O8)
      PH2OOO(9)=AMIN1(PH2OO(9),PH2O9)
      PH2OSO=0.375*PH2OOO(6)+0.375*PH2OOO(7)+0.125*PH2OOO
     $                (8)+0.125*PH2OOO(9)
      GO TO 1002
 1001 PH2OI(6)=VPP(TDEW)
      IF(IPURGE)PH2OI(6)=0.0
      PH2OI(7)=PH2OI(6)
      PH2OI(8)=PH2OI(6)
      PH2OI(9)=PH2OI(6)
      PH2OO(6)=FPH2OO(PH2OI(6),TUG(6),CMT(6),ACE(6),TG(6),WGE(6))
      PH2OO(7)=FPH2OO(PH2OI(7),TUG(7),CMT(7),ACE(7),TG(7),WGE(7))
      PH2OO(8)=FPH2OO(PH2OI(8),TUG(8),CMT(8),ACE(8),TG(8),WGE(8))
      PH2OO(9)=FPH2OO(PH2OI(9),TUG(9),CMT(9),ACE(9),TG(9),WGE(9))
      DUMMY=QLAT(28)*DUMMI/WGD6
      PH2O6 =PH2OI( 6)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(32)*DUMMI/WGD7
      PH2O7 =PH2OI( 7)+DUMMY*PG/(DUMMY+1.0)
      PH2OI(2)=AMIN1(PH2O6,PH2OO(6))
      PH2OI(3)=AMIN1(PH2O7,PH2OO(7))
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      PH2OOO(6)=PH2OI(2)
      PH2OOO(7)=PH2OI(3)
      PH2OO(2)=FPH2OO(PH2OI(2),TUG(2),CMT(2),ACE(2),TG(2),WGE(2))
      PH2OO(3)=FPH2OO(PH2OI(3),TUG(3),CMT(3),ACE(3),TG(3),WGE(3))
      DUMMY=QLAT(36)*DUMMI/WGD8
      PH2O8 =PH2OI( 8)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(40)*DUMMI/WGD9
      PH2O9 =PH2OI( 9)+DUMMY*PG/(DUMMY+1.0)
      PH2OI(4)=AMIN1(PH2O8,PH2OO(8))
      PH2OI(5)=AMIN1(PH2O9,PH2OO(9))
      PH2OOO(8)=PH2OI(4)
      PH2OOO(9)=PH2OI(5)
      PH2OO(4)=FPH2OO(PH2OI(4),TUG(4),CMT(4),ACE(4),TG(4),WGE(4))
      PH2OO(5)=FPH2OO(PH2OI(5),TUG(5),CMT(5),ACE(5),TG(5),WGE(5))
      DUMMY=QLAT(12)*DUMMI/WGD2
      PH2O2 =PH2OI( 2)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(16)*DUMMI/WGD3
      PH2O3 =PH2OI( 3)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(20)*DUMMI/WGD4
      PH2O4 =PH2OI( 4)+DUMMY*PG/(DUMMY+1.0)
      DUMMY=QLAT(24)*DUMMI/WGD5
      PH2O5 =PH2OI( 5)+DUMMY*PG/(DUMMY+1.0)
      PH2OI(1)=0.3*AMIN1(PH2O2,PH2OO(2))+0.3*AMIN1(PH2O3,PH2OO(3))+
     $         0.2*AMIN1(PH2O4,PH2OO(4))+0.2*AMIN1(PH2O5,PH2OO(5))
      PH2OO(1)=FPH2OO(PH2OI(1),TUG(1),CMT(1),ACE(1),TG(1),WGE(1))
      DUMMY=QLAT( 8)*DUMMI/WGD1
      PH2O1 =PH2OI( 1)+DUMMY*PG/(DUMMY+1.0)
      PH2OSO=AMIN1(PH2O1,PH2OO(1))
      PH2OOO(1)=PH2OSO
      PH2OOO(2)=AMIN1(PH2O2,PH2OO(2))
      PH2OOO(3)=AMIN1(PH2O3,PH2OO(3))
      PH2OOO(4)=AMIN1(PH2O4,PH2OO(4))
      PH2OOO(5)=AMIN1(PH2O5,PH2OO(5))
 1002 SQW=0.
      SQOSA=0.
      SQOSW=0.
      SQUG = QRSEN1 + QRSEN5 + QRSEN2 + QRSEN3 + QRSEN6
C
C   SQUG IS THE SUM OF THE SENSIBLE HEAT FROM THE MAN . IT IS THE TOTAL OF
C  THE Q FROM THE UNDERGARMENT TO THE GAS + Q FROM THE UNDERGARMENT
C  TO THE INSIDE OF THE SUIT + Q FROM THE MAN TO THE LIQUID COOLED GARMENT +
C  Q SENSIBLE RESPIRATORY.    THIS IS SUMMED IN FOLLOWING LOOP.
C
      SQUGW = 0.
      DO 105 I=1,10
      J=II(I)
      SQOSA=SQOSA+QOSA(I)
      SQOSW=SQOSW+QOSW(I)
      SQUG=SQUG+QUG(I)
      SQW=SQW+QW(I)
      QSEN(J)=QUGG(I)
      QRAD(J)=QUGIS(I)
      QLCG(J)=QW(I)
      EMAX(J)=WGE(I)*18.0/((PO2/PG*32.0+PN2/PG*28.0)*PG)*(PH2OO(I)-PH2OI
     $        (I))*1040.0
      EMAXT=WGE(I)*18.0/((PO2/PG*32.0+PN2/PG*28.0)*PG)*(VPP(TGOUT(I))-
     $      PH2OI(I))*1040.0
      EMAXM(J)=AMIN1(EMAX(J),EMAXT)
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      SQUGW = SQUGW + QUGIS(I)
  105 CONTINUE
      IF(MODE.EQ.3)EMAX(4)=0.126*ACE(10)*((TCAB+459.69)**1.04)*VEFF/
     $             100.0*SQRT(VCAB/PCAB)*(VPP(T(4))-VPP(TDEWC))
     $         *1.22
      IF(MODE.EQ.3)EMAX1=1.32*ACE(10)*(TCAB+460.0)*(VPP(T(4))-VPP(TDEWC)
     $       )*(PCAB*G*(ABS(0.005*PCAB*(T(4)-TCAB)+1.02*(VPP(T(4))-
     $          VPP(TDEWC)))))**0.25/PCAB*1.71
      IF(MODE.EQ.3.AND.EMAX1.GT.EMAX(4))EMAX(4)=EMAX1
C
      WO2OUT=WO2IN-O2RATE
      IF(MODE .EQ. 3) WO2OUT=WO2IN
      WCO2O=WCO2IN+CO2RAT
      IF (MODE .EQ. 3) WCO2O = WCO2IN
      SCAB1=SQOSA+SQOSW
      SCABC=0.
      DO 200 I=1,10
  200 SCABC=SCABC+QG(I)
      SCABC=SCABC+QRSE15
C
      CALL MAN
C
      TOSAV=0.
      TISAV=0.
      DO 155 I=1,10
      TISAV=TISAV + PCA(I)*TIS(I)
      TOSAV=TOSAV + PCA(I)*TOS(I)
  155 CONTINUE
      QSTOR=0.
      DO 112 I=1,41
      QSTOR=QSTOR+C(I)*(T(I)-TSET(I))
  112 CONTINUE
      STORAT=RM-(SQUG+TOTL)-U+QSHIV
      QTSUIT=0.0
      DO 2000 I=1,10
      IF(MODE .EQ. 3 .AND. I .EQ. 10) GO TO 2000
      QTSUIT=QTSUIT+AKS(I)/ALS(I)*(TIS(I)-TOS(I))*ACSUTE(I)
 2000 CONTINUE
      IF(MODE.EQ.3)GO TO 2001
C     PCO2HT=(T(NCO2)/VOLHMT*(TG(10)+459.69)*35.13)/144.0
C     NEW HELMET PCO2 LOGIC (JVI 6/88), SINCE T(NCO2) UNDEFINED.
C
      RHOCO2 = WCO2O / (60. * CFMS)
      PCO2HT = RHOCO2 * 35.10 * (TG(10)+459.67) / 144.
      HCO2MH=760.0/14.7*PCO2HT
 2001 CONTINUE
      RETURN
      END
      Real Function FPH2OO (FPH2OI,FTUG,FCMT,FACE,FTG,FWGE)

      COMMON/METCOM/ MODE,ICOND,INIT,IPURGE,II(10),CURVES,RM,UEFF,AC,AR,
     &       TCAB,TW,VCAB,PCAB,ALUG,AKUG,EUG,WF,TWI,CPW,UAG,
     &       DTIME,TDEWC,TDEW,U,ACSUIT(10),ARSUIT(10),CPG,CFMS,
     &       TGIN,PG,PO2,ALS(10),AKS(10),EIS(10),EOS(10),CPS(10),
     &       QASRB(10),VF,VEFF,WORK,TUGAV,WS(10),C(41),TWO,SQUG,
     &       QEVAP,TOTL,QSHIV,QSTOR,STORAT,SCAB1,CLO,TISAV,WG,
     &       TOSAV,TGOUTS,RMIX,PN2,QLCG(40),QSEN(40),QRAD(40),
     &       TSET(43),EMAX(40),PCFLO(5),G,TUG(10),TGOUT(10),TG(10),
```

```
&       TM(10),WH2OO,WO2OUT,WCO2O,WGOUT,SHSO,PULSE,QR,IPLOP,
&       TDEWA,SCABC,QRSEN1,QRSEN5,ACE(10),SQUGW,QLAT(40),
&       WGIN,VOLHMT,HCO2MH,QRSEN2,QRSEN3,QRSEN6,WH2OIN,QRSE15,QD
 VP1 = VPP(FTUG)
 EXPR = -FCMT*PG*FACE*144./(RMIX*(FTG+460.)*FWGE)
 FPH2OO=FPH2OI+(VP1-FPH2OI)* (1.-EXP(EXPR))
 End Function FPH2OO
```

J.12 SUBROUTINE SHIRT

```
      SUBROUTINE SHIRT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                           C
C SUBROUTINE SHIRT PROVIDES A MATH MODEL DESCRIBING THE HEAT AND MASS        C
C EXCHANGE BETWEEN THE CREWMAN S BODY OR UNDERGARMENT AND CABIN GAS, AND    C
C HEAT EXCHANGE BETWEEN THE CREWMAN S BODY OR UNDERGARMENT AND THE CABIN    C
C WALL.                                                                     C
C                                                                           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      PARAMETER (MM=71,M2=MM+2)
      LOGICAL INIT,IPURGE,CURVES
      DOUBLE PRECISION QVECTS
      DIMENSION TIS(10),TOS(10),BF(40)
      DIMENSION PCA(10),ARE(10)
      DIMENSION QSOL(10)
      DIMENSION XSHCO1(10),XSHCO2(10)
      DIMENSION SHCO1(10),SHCO2(10)
C
      EQUIVALENCE(T(42),TIS(1)),(T(52),TOS(1))
C
      COMMON/SOL/ARTOT1,AVRTOT,SQABS,ITIME
      COMMON/METCOM/ MODE,ICOND,INIT,IPURGE,II(10),CURVES,RM,UEFF,AC,AR,
     &       TCAB,TW,VCAB,PCAB,ALUG,AKUG,EUG,WF,TWI,CPW,UAG,
     &       DTIME,TDEWC,TDEW,U,ACSUIT(10),ARSUIT(10),CPG,CFMS,
     &       TGIN,PG,PO2,ALS(10),AKS(10),EIS(10),EOS(10),CPS(10),
     &       QASRB(10),VF,VEFF,WORK,TUGAV,WS(10),C(41),TWO,SQUG,
     &       QEVAP,TOTL,QSHIV,QSTOR,STORAT,SCAB1,CLO,TISAV,WG,
     &       TOSAV,TGOUTS,RMIX,PN2,QLCG(40),QSEN(40),QRAD(40),
     &       TSET(43),EMAX(40),PCFLO(5),G,TUG(10),TGOUT(10),TG(10),
     &       TM(10),WH2OO,WO2OUT,WCO2O,WGOUT,SHSO,PULSE,QR,IPLOP,
     &       TDEWA,SCABC,QRSEN1,QRSEN5,ACE(10),SQUGW,QLAT(40),
     &       WGIN,VOLHMT,HCO2MH,QRSEN2,QRSEN3,QRSEN6,WH2OIN,QRSE15,QD
      COMMON/GFC/SUBIN,SUBOUT,PH2OSO,MODEO
      COMMON/DWC/TIME
      COMMON/TMAT/QVECTS(MM),QVECT(MM),TDIFF,QVECST,
     $       PREC,DONT,HELP,OLDT,H,ENDONX,XHAT,OKPC,TRAN,WGE10,
     $       NCO2,T(M2),NMT,IQ,ICYCLE,IFLG,NB(MM),MINUT,INITL
      COMMON/BSIZE/BRM
      COMMON/RATSH/RSHCO1(10),RSHCO2(10)
      COMMON/BLUD/TBF,TSBF,BF,SROR
      COMMON/SKIN/TAVSKN
      COMMON/UAGNEW/CCUAG(26),NPUAG
      SAVE
C
      DATA(PCA(I),I=1,10)/0.3602,0.06705,0.06705,0.1587,0.1587,0.025,
     $                    0.025,0.0343,0.0343,0.07/
      DATA(XSHCO1(I),I=1,10)/1.02,1.74,1.74,1.54,1.54,3.19,3.19,
     $                       3.10,3.10,1.22/
      DATA(XSHCO2(I),I=1,10)/1.15,1.17,1.17,1.07,1.07,1.22,1.22,
     $                       1.14,1.14,1.71/
      II = ( /8,12,16,20,24,28,32,36,40,4/ )

C
C  J SUBSCRIPTS IN THIS SUBROUTINE 1=TRUNK 2=RIGHT ARM 3=LEFT ARM
C              4=RIGHT LEG 5=LEFT LEG 6=RIGHT HAND 7=LEFT HAND
C              8=RIGHT FOOT 9=LEFT FOOT 10=HEAD
```

```
C
      IF(CURVES) GO TO 80
      IF (.NOT. INIT) GO TO 100
   80 CONTINUE
      DO 101 I=1,10
         ACE(I)=PCA(I)*AC
         ARE(I)=PCA(I)*AR
         SHCO1(I)=XSHCO1(I)*RSHCO1(I)
         SHCO2(I)=XSHCO2(I)*RSHCO2(I)
 101  CONTINUE
      U=UEFF/100.0*(RM-278.0)
      WORK=RM-BRM-U
C
      IF(.NOT. INIT) GO TO 100
      IF(ICOND .GT. 0) GO TO 110
      DO 102 I=1,10
         J=II(I)
         TUG(I)=T(J)
  102 CONTINUE
  110 CONTINUE
      INIT=.FALSE.
C
C
C  THE PRECEDING STATEMENTS WILL BE EXECUTED ONLY ON THE INITIAL CALL OF
C  SUBROUTINE SHIRT FOR ANY GIVEN SET OF CONDITIONS
C
C
  100 SQUGA=0.
      SQUGW=0.
      SQW=0.
      TAVSKN=0.446*T(8)+0.0826*T(12)+0.0826*T(16)+0.1945*T(20)+0.1945*
     $                                                   T(24)
C
      VPDEW=VPP(TDEWC)
      TWR=TW+460.0
      TOLAT=TOTL+SROR
      IF (WF .GT. 0.) THEN
         CALL LAGIN(1,CCUAG,NPUAG,2,TOLAT,UAG)
         UAG=UAG*(1.0-1.08*EXP(-0.0166*WF))
         IF(UAG.LT.0.0) UAG=0.0
         DTLCG=(1.0-EXP(-UAG/(WF*CPW)))*(TAVSKN-TWI)
      ELSE
         DTLCG = 0.
         UAG = 0.
      ENDIF
      TWO = TWI + DTLCG
      IF(ITIME.LE.0.0)GO TO 5001
      QSOL1=0.2*SQABS*ARTOT1
      QSOL(10)=QSOL1+(ARE(10)-0.2)*AVRTOT*SQABS
      QSOL(1)=QSOL1+(ARE(1)-0.2)*AVRTOT*SQABS
      DO 5000 N=2,9
         QSOL(N)=SQABS*ARE(N)*AVRTOT
 5000 CONTINUE
 5001 CONTINUE
      DO 103 I=1,10
         J=II(I)
         TUGR=TUG(I)+460.
         HC=0.0212*ACE(I)*SQRT(PCAB*VCAB)
```

```
     $            *SHCO1(I)
        HC1=0.06*ACE(I)*(PCAB**2*G*ABS(TUG(I)-TCAB))**.25
     $            *SHCO2(I)
        IF( HC1 .GT. HC) HC=HC1
        HR=0.1713E-8*ARE(I)*EUG*(TUGR**3+TUGR*TUGR*TWR+TUGR*TWR*TWR+
     $  TWR**3)*VF
C
        QW = 0.0
        IF(I.GT.5)GO TO 104
        TUG(I)=(HR*TW+HC*TCAB+ACE(I)/CLO*T(J))/(HR+HC+ACE(I)/CLO)
        QW = PCFLO(I) * WF * CPW * DTLCG                                  4
        GO TO 105
  104   TUG(I)=T(J)
  105   QUGW=HR*(TUG(I)-TW)
        IF(ITIME.GT.0.0)QUGW=QUGW-QSOL(I)
        QUGA=HC*(TUG(I)-TCAB)
        SQUGW=SQUGW+QUGW
        SQUGA=SQUGA+QUGA
        SQW=SQW+QW
        QSEN(J)=QUGA
        QRAD(J)=QUGW
        QLCG(J)=QW
  103 CONTINUE
      QRSEN1=0.5*0.0418*PCAB*144.0/(48.3*(TCAB+459.69))*RM*CPG*((0.385*T
     $(1)+0.086*T(2)+0.0287*T(3)+0.238*T(5)+0.2615*T(6))-TCAB)
      QRSEN2 = 0.172 * QRSEN1
      QRSEN3 = 0.0574 * QRSEN1
      QRSEN6 = 0.523 * QRSEN1
      QRSEN5 = 0.476 * QRSEN1
      QRSEN1=0.771*QRSEN1
      QRSE15=QRSEN1+QRSEN5+QRSEN2+QRSEN3+QRSEN6
C
C
      SCABC=QRSE15+SQUGA
      SCAB1=SQUGA+SQUGW
      SQUG = SQUGA + SQUGW + SQW + QRSEN1 + QRSEN5 + QRSEN2 + QRSEN3 +
     $QRSEN6
      TUGAV=0.3317*TUG(1)+0.104*TUG(2)+0.104*TUG(3)+0.23015*TUG(4)+
     $       0.23015*TUG(5)
C
C  CALCULATE MAXIMUM EVAPORATION RATE
C
      DO 106 I=1,10
        J=II(I)
        VPTUG=VPP(TUG(I))
        EMAX(J)=.126*ACE(I)*((TCAB+460.)**1.04)*VEFF/100.*
     $  SQRT(VCAB/PCAB)*(VPTUG-VPDEW)
     $            *SHCO1(I)
        EMAX1=1.32*ACE(I)*(TCAB+460.)*(VPTUG-VPDEW)*(PCAB*G*(ABS(.005
     $  *PCAB*(TUG(I)-TCAB)+1.02*(VPTUG-VPDEW))))**.25/PCAB
     $            *SHCO2(I)
        IF (ABS(EMAX1).GT. ABS(EMAX(J)))EMAX(J)=EMAX1
  106 CONTINUE
C
C
      CALL MAN
C
      QSTOR=0.
```

```
      DO 112 I=1,41
         QSTOR=QSTOR+C(I)*(T(I)-TSET(I))
  112 CONTINUE
      STORAT=RM-(SQUGA+SQUGW+SQW+TOTL+QRSEN1+QRSEN2+QRSEN3+QRSEN6+
     $    QRSEN5)-U+QSHIV
      RETURN
C
      END
```

J.13 SUBROUTINE MAN

```
      SUBROUTINE MAN
      PARAMETER (MM=71,M2=MM+2)
      LOGICAL INIT,IPURGE
      LOGICAL DONT,ENDONX,OKPC,HELP,TRAN
      LOGICAL IPLOP
      DOUBLE PRECISION QVECTS
C
      DIMENSION OLDY(MM)
      DIMENSION QCONV(40),QCOND(40),BF(40),QMET(40),TEST(41),WARM(41),
     $          COLD(41),PH2OO(10),PH2OI(10),PLMSPR(10)
      DIMENSION WORKM(10),CHILM(10),SKINV(10),SKINC(10),
     $          SKINS(10)
      DIMENSION CCVEFM(22)
      DIMENSION EMAXF(40)
C
      EQUIVALENCE (TSKIN,T(42)),(TCORE,T(1))
C
      COMMON/METCOM/ MODE,ICOND,INIT,IPURGE,II(10),CURVES,RM,UEFF,AC,AR,
     &       TCAB,TW,VCAB,PCAB,ALUG,AKUG,EUG,WF,TWI,CPW,UAG,
     &       DTIME,TDEWC,TDEW,U,ACSUIT(10),ARSUIT(10),CPG,CFMS,
     &       TGIN,PG,PO2,ALS(10),AKS(10),EIS(10),EOS(10),CPS(10),
     &       QASRB(10),VF,VEFF,WORK,TUGAV,WS(10),C(41),TWO,SQUG,
     &       QEVAP,TOTL,QSHIV,QSTOR,STORAT,SCAB1,CLO,TISAV,WG,
     &       TOSAV,TGOUTS,RMIX,PN2,QLCG(40),QSEN(40),QRAD(40),
     &       TSET(43),EMAX(40),PCFLO(5),G,TUG(10),TGOUT(10),TG(10),
     &       TM(10),WH2OO,WO2OUT,WCO2O,WGOUT,SHSO,PULSE,QR,IPLOP,
     &       TDEWA,SCABC,QRSEN1,QRSEN5,ACE(10),SQUGW,QLAT(40),
     &       WGIN,VOLHMT,HCO2MH,QRSEN2,QRSEN3,QRSEN6,WH2OIN,QRSE15,QD
      COMMON/PRESS/PH2OO,PH2OI,PH2OOO(10)
      COMMON/DAVE/PH2O10
      COMMON/SWEAT/SWEAT,QDIF(40)
      COMMON/HUDUNT/QMET,QCOND,QCONV
      COMMON/DWC/TIME
      COMMON/TMAT/QVECTS(MM),QVECT(MM),TDIFF,QVECST,
     $       PREC,DONT,HELP,OLDT,H,ENDONX,XHAT,OKPC,TRAN,WGE10,
     $       NCO2,T(M2),NMT,IQ,ICYCLE,IFLG,NB(MM),MINUT,INITL
      COMMON/LCG/ WDOT1,UASB,EL,EL2,DE,WT,CPHX,WTDUCT,CPDUCT,WTDUC2,
     $  ELP,ELP2,DEP,RHOC,WTPIPE,WTPIP2,CPP,SUBKA,UAHXS,WN2
      COMMON/POSTL/ RGAS,PA,CFMC,DENSA,NUMEN,AREAW,VOLCAB,RHOCOA,TATM,
     $ CO2MMH,IQV,CPA,QCNDEN
      COMMON/BLUD/TBF,TSBF,BF,SROR,EMTOT
      COMMON/EMAX/EMAXM(40)
      COMMON/BSIZE/BRM,QB(40),BFB(40),FACTOR(40),WMUSC,WSKIN
      COMMON/CHGTGI/TAVD,TAVD2,TAVP,TAVP2
      SAVE
      DATA CCVEFM/0.0,0.0,0.35,0.35,0.5,0.48,0.8,0.68,1.0,0.8,
     $            1.2,0.88,1.4,0.95,1.6,0.97,1.8,0.99,2.0,1.0,10.0,1.0/
      DATA NPVEFM/11/
      DATA CSW,SSW,PSW,CDIL,SDIL,PDIL,CCON,SCON,PCON,CCHIL,SCHIL,PCHIL
     $    /884.0,0.0,73.4,183.5,0.0,0.0,5.55,5.55,0.0,0.0,0.0,12.22/
      DATA BFB/105.6,0.594,0.264,3.7,510.0,14.08,5.06,4.62,0.759,1.364,
     $         0.352,0.55,0.759,1.364,0.352,0.55,2.32,4.07,0.88,3.135,
     $         2.32,4.07,0.88,3.135,0.11,0.055,0.055,2.2,0.11,0.055,
     $         0.055,2.2,0.165,0.033,0.088,3.3,0.165,0.033,0.088,3.3/
      DATA QB/44.6,1.075,0.498,0.243,156.3,25.4,9.32,1.222,1.37,2.485,
     $        0.648,0.2185,1.37,2.485,0.648,0.2185,4.44,7.37,1.593,
```

```
     $        0.538,4.44,7.37,1.593,0.538,0.1733,0.0539,0.0997,0.0817,
     $        0.1733,0.0539,0.0997,0.0817,0.289,0.0539,0.1493,0.1077,
     $        0.289,0.0539,0.1493,0.1077/
      DATA WORKM/0.0,0.3,0.04,0.04,0.3,0.3,0.005,0.005,0.005,0.005/
      DATA CHILM/0.023,0.948,0.00265,0.00265,0.0095,0.0095,0.00115,
     $           0.00115,0.0012,0.0012/
      DATA SKINV/0.132,0.322,0.0475,0.0475,0.115,0.115,0.061,0.061,
     $           0.05,0.05/
      DATA SKINC/0.05,0.15,0.025,0.025,0.025,0.025,0.175,0.175,0.175,
     $           0.175/
      DATA SKINS/0.482,0.077,0.077,0.1095,0.1095,0.0155,0.0155,0.0175,
     $           0.0175,0.081/
      DATA FACTOR/8.85,12.82,22.60,0.0,3.09,10.70,28.05,0.0,3.18,8.32,
     $            22.80,0.0,3.18,8.32,22.80,0.0,5.75,18.70,33.50,0.0,
     $            5.75,18.70,33.50,0.0,4.50,8.32,9.41,0.0,4.50,8.32,
     $            9.41,0.0,5.54,13.36,11.93,0.0,5.54,13.36,11.93,0.0/
C
      II = ( /8,12,16,20,24,28,32,36,40,4/ )
C
C  EVAPORATION
C  CALCULATE SWEAT + SHIVER
C
      DO 52 I=1,40
      TEST(I)=T(I)-TSET(I)
      WARM(I)=0.0
      COLD(I)=0.0
      IF(TEST(I))53,54,55
   53 COLD(I)=-TEST(I)
   54 GO TO 52
   55 WARM(I)=TEST(I)
   52 CONTINUE
C
      WARMS=0.0827*WARM(4)+0.587*WARM(8)+0.0411*WARM(12)+0.0411*WARM(16)
     $     +0.093*WARM(20)+0.093*WARM(24)+0.011075*WARM(28)+0.011075*
     $      WARM(32)+0.01995*WARM(36)+0.01995*WARM(40)
      COLDS=0.0827*COLD(4)+0.587*COLD(8)+0.0411*COLD(12)+0.0411*COLD(16)
     $     +0.093*COLD(20)+0.093*COLD(24)+0.011075*COLD(28)+0.011075*
     $      COLD(32)+0.01995*COLD(36)+0.01995*COLD(40)
      WARMM=0.417*WARM(6)+0.095*WARM(10)+0.095*WARM(14)+0.1965*WARM(18)+
     $      0.1965*WARM(22)
      COLDM=0.417*COLD(6)+0.095*COLD(10)+0.095*COLD(14)+0.1965*COLD(18)+
     $      0.1965*COLD(22)
      SWEAT=CSW*WARM(1)+SSW*WARMS+PSW*WARM(1)*WARMS
      DILAT=CDIL*WARM(1)+SDIL*WARMS+PDIL*WARM(1)*WARMS
      STRIC=CCON*COLD(1)+SCON*COLDS+PCON*COLD(1)*COLDS
      QSHIV=CCHIL*COLD(1)+SCHIL*COLDS+PCHIL*COLD(1)*COLDS
      SWEAT=SWEAT*WSKIN/3.55
      DILAT=DILAT*WSKIN/3.55
      STRIC=STRIC*WSKIN/3.55
      QSHIV=QSHIV*WMUSC/30.56
      QLAT(1)=0.5*0.0418*PCAB*144.0/(48.3*(TCAB+459.69))*RM*(VPP(0.385*
     $T(1)+0.086*T(2)+0.0287*T(3)+0.238*T(5)+0.2615*T(6))-VPP
     $(TDEWC))*((18.0*1040.0)/(32.0*PCAB))
      TINP1 = 0.385*T(1)+0.086*T(2)+0.0287*T(3)+0.238*T(5)+0.2615*T(6)
      VP1 = VPP(TINP1)
      VP2 = VPP(TDEWC)
      QLAT(1)=0.5*0.0418*PCAB*144.0/(48.3*(TCAB+459.69))*RM*(VP1-VP2)
     &  *((18.0*1040.0)/(32.0*PCAB))
```

```
C        IF(MODE.NE.0.AND.MODE.NE.3)QLAT(1)=0.5*0.0418*PG*144.0/
C      $(48.3*(TG(10)+459.69))*RM*(VPP(0.385*T(1)+0.086*T(2)+0.0287*T(3)
C      $+0.238*T(5)+0.2615*T(6))-((PH2OI(10)+
C      $  AMIN1(PH2O10,PH2OO(10)))/2.0))*((18.0*1040.0)/(32.0*PG))
      IF(MODE.NE.0.AND.MODE.NE.3)Then
         TINP1=0.385*T(1)+0.086*T(2)+0.0287*T(3)+0.238*T(5)+0.2615*T(6)
         VP1 = VPP(TINP1)
         PINP1 = AMIN1(PH2O10,PH2OO(10))
         PAVG = (PH2OI(10)+PINP1)/2.0
         DENOM = (48.3*(TG(10)+459.69))
         QLAT(1)=0.5*0.0418*PG*144.0/DENOM*RM*(VP1-PAVG)*
     &           ((18.0*1040.0)/(32.0*PG))
      End If
      QLAT(2)=0.172 * QLAT(1)
      QLAT(3)=0.0574 * QLAT(1)
      QLAT (5) = 0.476 * QLAT(1)
      QLAT (6) = 0.523 * QLAT (1)
      QLAT (1) = 0.771 * QLAT (1)
      QR=QLAT(1)+QLAT(5)+QLAT(2)+QLAT(6)+QLAT(3)
C
C   DIFFUSION
C
      VAPPUG=VPP(TDEWC)
      IF(MODE.NE.0)GO TO 100
      DO 1000 I=1,10
      J=II(I)
      QDIF(J)=6.66*(VPP(TUG(I))-VAPPUG)*ACE(I)
 1000 CONTINUE
  101 CONTINUE
      SROR=0.0
      EMTOT = 0.
      QEVAP = 0.
      DO 1006 I=1,10
      J=II(I)
      QLAT(J)=QDIF(J)+SKINS(I)*SWEAT*2.0**((T(J)-TSET(J))/7.2)
      DUMMY=QLAT(J)/EMAX(J)
      CALL LAGIN(50,CCVEFM,NPVEFM,2,DUMMY,VEFFM)
      IF (EMAX(J) .LT. 0.) VEFFM = 1.
      EMAXV=EMAX(J)*VEFFM
      IF(MODE.EQ.0) GO TO 7900
      IF(MODE.EQ.3.AND.I.EQ.10) GO TO 7900
      EMAXF(J)=AMIN1(EMAXM(J),EMAXV)
      IF(MODE.EQ.3) GO TO 8000
C
      IF (I .EQ. 10 .AND. EMAX(4) .GT. 0.) THEN
         IF (QLAT(4) .GT. (EMAX(4) - QR)) QLAT(4) = EMAX(4) - QR
      ENDIF
C
      GO TO 8000
 7900 EMAXF(J)=EMAXV
 8000 CONTINUE
C
      IF (EMAXF(J) .LT. 0.) THEN
         SROR = SROR + QLAT(J) - 2. * QDIF(J)
         QLAT(J) = QDIF(J)
      ELSE
         IF(QLAT(J).GT.EMAXF(J)) SROR=SROR+QLAT(J)-EMAXF(J)
         IF(QLAT(J).GT.EMAXF(J)) QLAT(J)=EMAXF(J)
```

```
      ENDIF
C
      QEVAP = QEVAP + QLAT(J) - QDIF(J)
      EMTOT = EMTOT + EMAXF(J)
C
 1006 CONTINUE
      QD=QDIF(4)+QDIF(8)+QDIF(12)+QDIF(16)+QDIF(20)+QDIF(24)+QDIF(28)+
     $   QDIF(32)+QDIF(36)+QDIF(40)
      TOTL=QLAT(4)+QLAT(8)+QLAT(12)+QLAT(16)+QLAT(20)+QLAT(24)+QLAT(28)+
     $     QLAT(32)+QLAT(36)+QLAT(40)+QR
C
      TIME1=TIME
      DO 9401 I=1,10
      N=4*I-3
      BF(N)=BFB(N)
      QMET(N)=QB(N)
      QMET(N+1)=QB(N+1)+WORKM(I)*WORK+CHILM(I)*QSHIV
      BF(N+1)=BFB(N+1)+0.554*(QMET(N+1)-QB(N+1))
      QMET(N+2)=QB(N+2)
      BF(N+2)=BFB(N+2)
      QMET(N+3)=QB(N+3)
      BF(N+3)=(BFB(N+3)+SKINV(I)*DILAT)/(1.0+SKINC(I)*STRIC)
 9401 CONTINUE
      TSBF=BF(4)+BF(8)+BF(12)+BF(16)+BF(20)+BF(24)+BF(28)+BF(32)+BF(36)
     $          +BF(40)
C
C  CHECK FOR NEGATIVE BLOOD FLOW
C
      DO 32 I=1,40
   32 IF(BF(I).LT.0.0)BF(I)=0.0
C
C   QCONV(I)=CONVECTION FROM BLOOD TO EACH NODE
C   QCOND(I)=CONDUCTION BETWEEN ADJACENT NODES
C
      DO 40 I=1,40
      QCONV(I)=BF(I)*(T(41)-T(I))
      QCOND(I)=FACTOR(I)*(T(I)-T(I+1))
   40 CONTINUE
C
C  QSEN = CONVECTION TO GAS
C  QRAD = RADIATION
C  QSEN, QRAD, QLCG, EMAX ARE CALCULATED IN SUBROUTINES SUIT OR SHIRT
C
      IF(MODE .EQ. 0)GO TO 1650
      WH2OO=WH2OIN+TOTL/1040.
      IF(MODE .EQ. 3) WH2OO=WH2OIN+(TOTL-QLAT(4)-QR)/1040.
      WGOUT=WH2OO+WO2OUT+WCO2O+WN2
      SHSO=WH2OO/(WGOUT-WH2OO)
 1650 CONTINUE
      IF(TRAN) GO TO 1660
C
      CALL DERIV
C
      GO TO 1900
 1660 CONTINUE
C
      CALL CRANE
C
```

```
      IF(.NOT. IPLOP) GO TO 1690
      TCAB=T(IQV+2)
      IF (TCAB .LT. -459.67) TCAB = -459.67
      TW=T(IQV+3)
      RHOH2O = T(IQV) / VOLCAB
      VPPATN = RHOH2O * 85.76 * (TCAB+460.) / 144.
      HGMM=760.0/14.7*VPPATN
      TDEWC=DEWPT(HGMM)
      IF(TDEWC .GT. TCAB) TDEWC = TCAB
 1690 CONTINUE
      IF(MODE .EQ. 0 .OR. UASB .EQ. 0) GO TO 200
      IF(T(62) .GE. 32.) GO TO 200
      T(62)=32.
      INITL=0
      GO TO 1660
  200 CONTINUE
      IF(HELP)GO TO 250
      IF(TIME .LE. OLDT)GO TO 1660
      GO TO 500
  250 TIME=OLDT
      DO 300 I=1,NMT
      T(I)=OLDY(I)
  300 CONTINUE
      H=H*.3
      GO TO 1660
  500 OLDT=TIME
      DO 550 I=1,NMT
      OLDY(I)=T(I)
  550 CONTINUE
      IF(INITL .EQ. 1) GO TO 1660
C
C     CALCULATE AVERAGE SKIN TEMPERATURE(72) BASED ON PERCENTAGE OF
C  TOTAL SKIN AREA FOR EACH SKIN NODE * THAT NODES TEMPERATURE
C
      T(72)=0.07*T(4)+0.3602*T(8)+0.06705*T(12)+0.06705*T(16)+
     $    0.1587*T(20)+0.1587*T(24)+0.025*T(28)+0.025*T(32) +
     $    0.0343*T(36)+0.0343*T(40)
      T(73)=0.02325*T(2)+0.549*T(6)+0.0527*T(10)+0.0527*T(14)+0.1592*
     $    T(18)+0.1592*T(22)+0.00115*T(26)+0.00115*T(30)+0.00115*
     $    T(34)+0.00115*T(38)
 1900 CONTINUE
      TBF=0.0
      DO 1968 I=1,40
 1968 TBF=TBF+BF(I)
      PULSE=5.926*TBF/60.0
      RETURN
C
C  ** SUITED DIFFUSION REWRITTEN BY JVI, 3/17/89.
C
  100 DO 2000 NML=1,10
      J=II(NML)
      VPPTUG= VPP (TUG(NML))
      IF(MODE .EQ. 3 .AND. NML .EQ. 10) THEN
         PLMSPR(NML)= VPPTUG - VAPPUG
      ELSEIF (VPPTUG .LE. PH2OOO(NML)) THEN
         PLMSPR(NML)= VPPTUG - PH2OI(NML)
      ELSE
         RATIO= (VPPTUG - PH2OI(NML)) / (VPPTUG - PH2OOO(NML))
```

```
         IF (RATIO .EQ. 1.) THEN
            PLMSPR(NML)= 0.
         ELSEIF (RATIO .GT. 0.) THEN
            PLMSPR(NML)= (PH2OOO(NML) - PH2OI(NML))/ALOG(RATIO)
         ELSE
            PLMSPR(NML)= 0.
         ENDIF
      ENDIF
      QDIF(J)= 6.66*ACE(NML)*PLMSPR(NML)
 2000 CONTINUE
      GO TO 101
      END
```

J.14 SUBROUTINE CRANE

```
      SUBROUTINE CRANE
C     HELP IS LOGICAL VARIABLE SET TRUE IN DERIV WHEN
C          A DISCONTINUITY OCCURS AND IT IS NECESSARY TO DECREASE THE TIME
C          INCREMENT AND RESTART THE INTEGRATION BEFORE CONTINUING.
C          THE Y AND F ARRAYS AND X ARE RESET TO THEIR LAST GOOD VALUES
C          AND INIT SET EQUAL TO ZERO BEFORE PROCEDING WITH NEW H.
C     THE ARGUMENTS OF THIS SUBROUTINE ARE ALL CONTAINED IN THE FOLLOW- CRAN0020
C     ING COMMON STATEMENT, LABELED CRANEC.  DRIVER PROGRAM MUST CONFORMCRAN0030
C     IN ORDER AND DIMENSIONS WITHIN COMMON/CRANEC/,THOUGH NOT NECES-   CRAN0040
C     SARILY IN THE NAMES OF THE VARIABLES.                             CRAN0050
C                                                                       CRAN0060
C     CRANE HAS BEEN CHANGED FOR USE IN THE METABOLIC MAN PROGRAM.
C     THE MAXIMUM VALUE FOR N HAS BEEN CHANGED TO MM, AND THE COMMON
C     /CRANC/ AND COMMON/SCRAM/ HAVE BEEN REPLACED BY /TMAT/
C     VARIABLE INIT HAS BEEN CHANGED TO INITL
C     COMMON /CRANEC/ X,Y(40),F(40),H,N,NB(40),MIN,PREC,DONT,INIT,
C    *  ENDONX,XHAT,OKPC
C     COMMON/SCRAM/ HELP,DIVERG
C
      DOUBLE PRECISION QVECTS
      LOGICAL DONT, ENDONX, OKPC, HELP
C      PARAMETER MM=71,M2=MM+2
C  UNIX 8/00, JVI
      PARAMETER (MM=71,M2=MM+2)
      DIMENSION F(MM)
      COMMON/DWC/TIME
C*****THE PROGRAM VARIABLE T IS CHANGED TO Y IN SUBROUTINE CRANE ONLY****
      COMMON/TMAT/QVECTS(MM),QVECT(MM),TDIFF,QVECST,
     $       PREC,DONT,HELP,OLDT,H,ENDONX,XHAT,OKPC,TRAN,WGE10,
     $       NCO2,Y(M2),NMT,IQ,ICYCLE,IFLG,NB(MM),MINUT,INITL
      EQUIVALENCE(F(1),QVECT(1)),(TIME,X),(NMT,N)
C                                                                       CRAN0080
C       MEANING OF THE ARGUMENTS ARE AS FOLLOWS                         CRAN0090
C      X    THE INDEPENDENT VARIABLE.                                   CRAN0100
C      Y    ARRAY OF DEPENDENT VARIABLES, 40 MAXIMUM.                   CRAN0110
C      F    ARRAY OF DERIVATIVES, FUNCTIONS OF X AND THE Y VECTOR.      CRAN0120
C      H    STEP SIZE IN X.  MUST BE NON-ZERO.  USUALLY MAY BE ALTERED  CRAN0130
C           INTERNALLY BY CRANE, AFTER FIRST BEING SET + OR - EXTERNALLY.CRAN0140
C      N    THE NO. OF Y S AND F S IN THE SYSTEM.  USUALLY THE NO. ALSO CRAN0150
C           OF COUPLED ORDINARY DIFF. EQUNS.                            CRAN0160
C     NB   AN ARRAY OF FLAGS.  IF +, HOLD ABSOLUTE TRUNCATION ERROR EST.CRAN0170
C                                 BELOW A SPECIFIED LIMIT =10.**(-PREC) CRAN0180
C                              IF 0, DITTO FOR RELATIVE TRUNCATION ERRORCRAN0190
C                                 ESTIMATE.                             CRAN0200
C                              IF -, DISREGARD THE TRUNC. ERROR. EST.   CRAN0210
C                                 FOR THE Y S WHOSE FLAGS ARE NEGATIVE. CRAN0220
C     MIN  THE MINIMUM NO. OF STEPS BETWEEN OCCASIONS FOR DOUBLING H.   CRAN0230
C           THE VALUE OF MIN MAY NOT EXCEED 10, NOR BE LESS THAN 3.     CRAN0240
C     INIT SET TO ZERO BEFORE FIRST CALL, CAUSING THE SR TO INITIALIZE  CRAN0250
C           ITSELF.  THEREAFTER, INIT IS BUMPED  INTERNALLY, EACH STEP.  CRAN0260
C     DONT A FLAG WHICH IF TRUE FORBIDS ANY CHANGE IN H TO BE MADE
C           INTERNALLY BY THE SR. (UNLESS ENDONX=T)
C     PREC A POSITIVE CONST. APPROXIMATELY EQUAL TO THE NO. OF SIGNIFI- CRAN0290
C           CANT DECIMAL DIGITS OF LOCAL PRECISION.  (BASED ON TRUNCATIONCRAN0300
C           ERROR ESTIMATES MADE INTERNALLY.  EFFECTIVE ONLY IF DONT=T.)
C     ENDONX A FLAG WHICH IF SET TRUE IN CALLING ROUTINE AND ACCOMPANIED
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C          BY A VALUE OF XHAT .GT. X AT INIT=0 FOR H .GT. 0. (OR XHAT
C          .LT. X IF H .LT. 0.) WILL ENABLE SR TO RETURN TO CALLING
C          PROGRAM WITH X=XHAT AND ENDONX SET FALSE AS A FLAG TO THIS
C          EFFECT. DONT WILL BE IGNORED IN THIS INSTANCE.
C     XHAT VALUE OF X, IDEPENDENT SEGMENT, AT WHICH A DISCONTINUITY
C          OCCURS. USED IN CONJUNCTION WITH ENDONX TO HAVE X=XHAT AT END
C          OF A STEP.
C     OKPC A FLAG TO INDICATE THAT AT LEAST ONE PREDICTOR-CORRECTOR STEP
C          WHICH SATISFIES THE ERROR CRITERIA HAS BEEN TAKEN.
C                                                                       CRAN0320
C        THE PARTICULAR PREDICTOR-CORRECTOR ALGORITHM IS THAT PUBLISHED CRAN0330
C     BY CRANE AND KLOPFENSTEIN IN J.A.C.M. VOL 12, PAGES 227-241, APRILCRAN0340
C     1965.  IT IS OF FOURTH ORDER, I.E., TRUNCATION ERRORS ARE OF ORDERCRAN0350
C     H**5.  THE ALGORITHM WAS DEVELOPED TO MAXIMIZE THE RANGE OF STEP  CRAN0360
C     SIZE CONSISTENT WITH ABSOLUTE STABILITY, AND IN A LOOSER SENSE, TOCRAN0370
C     HAVE A GOOD RANGE OF RELATIVE STABILITY.  THESE RANGES, EXPRESSED CRAN0380
C     AS H,NORMALIZED BY MULTIPLYING BY PARTIAL DERIV OF Y(=G(X,Y)) WITHCRAN0390
C     RESPECT TO Y, ARE                                                 CRAN0400
C                    FOR ABSOLUTE,  0.GE.HBAR.GE.(-2.4809)              CRAN0410
C                    FOR RELATIVE,  INFINITY.GE.HBAR.GE.(-.446)         CRAN0420
C        THE STARTING PROCEDURE IS THE RUNGE-KUTTA VARIANT PUBLISHED BY CRAN0430
C     S. GILL, CAMB. PHIL. SOC. PROC., 47, P96,(1951)                   CRAN0440
C                                                                       CRAN0450
C          TO USE THIS ROUTINE, A SUBROUTINE CALLED DERIV MUST BE PROVI-CRAN0460
C     DED WHICH USES LABELED COMMON/CRANEC/AND CALCULATES THE F VECTOR. CRAN0470
C     THE FIRST CALL OF CRANE WILL ONLY OBTAIN F S,AND SET INIT=1. EACH CRAN0480
C     SUBSEQUENT CALL WILL ADVANCE ONE STEP AND UPDATE X,Y AND F, EXCEPTCRAN0490
C     THAT AFTER THREE STEPS, CRANE MAY HALVE H AND RETURN TO INITIAL   CRAN0500
C     CONDITIONS WITH INIT=4.  (THIS BEHAVIOR WILL RECUR UNTIL PRECISIONCRAN0510
C     IS SATISFIED ACCORDING TO AN ERROR ESTIMATE AFTER THREE STEPS.)   CRAN0520
C                                                                       CRAN0530
C          PRIOR TO FIRST CALL, SET INIT X AND Y AND DEFINE THE VALUES  CRAN0540
C     OF THE NB VECTOR, ALSO DEFINE VALUES OF N,MIN,INIT(=0),IDONT, AND CRAN0550
C     PREC.  PREC SHOULD ADVISEDLY BE FROM 2.5 TO 7. (NOT NECESSARILY   CRAN0560
C     AN INTEGER), THOUGH THERE WILL BE NO EFFECT IF IDONT.NE.0         CRAN0570
C                                                                       CRAN0580
C          PRINTOUT AND TERMINATION ARE NOT ACCOMPLISHED BY CRANE. (NOT)CRAN0590
C                                                                       CRAN0600
C          DO NOT CHANGE X,Y,F,N OR H EXTERNALLY UNLESS YOU SET INIT=0, CRAN0610
C     EXTERNALLY.  HOWEVER, NB AND PREC MAY BE CHANGED AT ANY TIME. SET-CRAN0620
C     TING INIT.LT.0 WILL RESULT IN INHIBITING INCREASE IN H FOR MIN    CRAN0630
C     STEPS, BUT WILL PERMIT DECREASES IN H.  INIT WILL BE POSITIVE ON  CRAN0640
C     EXITTING CRANE AGAIN.                                             CRAN0650
      DIMENSION Q(MM),Y1(MM),Y0(MM),F0(MM),F1(MM),F2(MM),F3(MM),F4(MM),
     1 F5(MM),Y2(MM),E(10),Y3(MM),Y4(MM),Y5(MM)
      EQUIVALENCE( Y5(1),Q(1)),(R,T)                                    CRAN0680
C       Y5 AND Q ARE NOT BOTH NEEDED AT THE SAME INSTANT.               CRAN0690
      DATA VNU /.14011612E-07/
      DATA BETA,PRECN,BOUNDB,BOUNDA,BOUND/0.,0.,0.,0.,0./
      DATA KT,K,IS,H1,KBC,AK,S/0,0,0,0.,0,0.,0./
C     VNU      MAXIMUM ROUNDOFF ERROR ON UNIVAC 1108 CALCULATED BY
C          V=ALPHA*BASE**(1-IT) WHERE ALPHA = 1. FOR ROUNDING MACHINE
C          AND .5 FOR TRUNCATING MACHINE. BASE IS THE NUMBER BASE FOR
C          MACHINE (2 FOR 1108). IT IS NUMBER OF DIGITS IN MANTISSA OF
C          THE WORD IN MEMORY ( 27 FOR 1108 ).
C     FIRST EXECUTABLE NEXT                                             CRAN0710
C
C*****                                                                  ********
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      IF(INITL)1,2,3
    1 INITL=0
      E(MINUT)=10.                                                        CRAN0740
    2 IF(N .GT. 0 .AND. N .LE. MM) GO TO 5
      WRITE (2,200)
  200 FORMAT(54H0N WAS NOT A POSITIVE INTEGER.LT.40, ON CALLING CRANE.) CRAN0790
      CALL EXIT                                                         CRAN0800
 5    IF ( MINUT .LT. 3 ) MINUT=3
      IF ( MINUT .GT. 10 ) MINUT=10
      IF ( ENDONX .AND. (XHAT-X)/H .LE. 0.) GO TO 2040
      BETA   = -ALOG10(VNU)*.9
 70   IF ( PREC-BETA ) 11,13,12
 12   PREC   = BETA
 11   IF ( PREC .LT. 2. ) PREC=4.
C      STATEMENT 11 ASSUMES THAT THE OVERSIGHT OF SPECIFYING NO PRECI-  CRAN0900
C     SION, OR PRECISION BELOW 2.0 DECIMALS, SHOULD CALL FOR 4 DECIMALS,CRAN0910
C     VIA INTERNAL CORRECTION. ALSO, PREC ABOVE MACHINE ACCURACY IS
C     REDUCED TO MACHINE ACCURACY.
   13 PRECN=PREC                                                        CRAN0930
      T=10.**(-PREC)                                                    CRAN0940
      BOUNDB=T*16.21966                                                 CRAN0950
      BOUNDA=T*.05                                                      CRAN0960
      BOUND=BOUNDA*FLOAT(MINUT)                                         CRAN0970
      IF(INITL)1155,1155,16
 1155 CALL DERIV                                                        CRAN0990
      IF (HELP) GO TO 2000
      ASSIGN 18 TO KT
C*****RUNGE-KUTTA SETUP
   17 K=0                                                               CRAN1000
      IF ( ENDONX .AND. (XHAT-X)/(4.*H) .LE. 1. ) H=(XHAT-X)/4.
      ASSIGN 55 TO IS                                                   CRAN1010
      H1=.5*H                                                           CRAN1020
      KBC=3                                                             CRAN1030
      OKPC   = .FALSE.
      GO TO KT,(18,20)
C     IF PROGRAM HAS BACKED UP TO START OF A R-K GO TO 18.
C     IF PROGRAM HAS BACKED UP TO LAST PC THEN GO TO 20.
C     THIS WILL PERMIT PRINTOUT TO 'START OVER'.
C     ALSO FIRST CALL WITH INIT=0 WILL ALSO PASS THRU 18.
C*****END R-K SETUP
C     THIS IS THE NORMAL CALL OF DERIV WITH A NEW PC Y VECTOR, HENCE
C     A USEABLE VALUE OF F IF HELP=FALSE.
   15 CALL DERIV                                                        CRAN1050
      IF (HELP) GO TO 52
   18 INITL=1+INITL
      IF ( ENDONX .AND. ABS( (XHAT-X)/XHAT ) .LT. VNU *10.)
     .  ENDONX=.FALSE.
   19 IF(OKPC .OR. INITL.EQ. 1) GO TO 999
      GO TO 14
  999 RETURN
   14 CONTINUE
C      THE ABOVE IS THE ONLY RETURN FROM INTODE.  NEXT IS REACHED WHEN  CRAN1080
C     INIT EXCEEDS 0.                                                   CRAN1090
C*****                                                                  ********
C
 3    IF(ABS(PREC-PRECN) .GT. .1E-7) GO TO 70
 16   IF ( DONT .AND. OKPC ) GO TO 213
      IF ( OKPC ) GO TO 212
```

```
C
   20 K=4                                                               CRAN1120
  213 DO 22 I=1,N                                                       CRAN1130
      F3(I)=F2(I)                                                       CRAN1140
      F2(I)=F1(I)                                                       CRAN1150
      F1(I)=F0(I)                                                       CRAN1160
      F0(I)=F(I)                                                        CRAN1170
      Y3(I)=Y2(I)                                                       CRAN1180
      Y2(I)=Y1(I)                                                       CRAN1190
      Y1(I)=Y0(I)                                                       CRAN1200
   22 Y0(I)=Y (I)                                                       CRAN1210
      IF ( KBC .EQ. 0 .OR. DONT ) GO TO 23
   24 KBC=KBC-1                                                         CRAN1230
      XN=X+H                                                            CRAN1240
      X=X+H1                                                            CRAN1250
      RX=.292893219                                                     CRAN1260
      ASSIGN 33 TO KS                                                   CRAN1270
C***** START OF ONE RK STEP                                             ********
   37 DO 29 I=1,N                                                       CRAN1280
      AK=H*F(I)                                                         CRAN1290
      GO TO KS,(33,34,30)                                               CRAN1300
   33 Y(I)=Y(I)+0.5*AK                                                  CRAN1310
      Q(I)=AK                                                           CRAN1320
      GO TO 29                                                          CRAN1330
   30 Y(I)=(-Q(I)-Q(I)+AK)*.166666667+Y(I)                              CRAN1340
      GO TO 29                                                          CRAN1350
   34 R=RX*(AK-Q(I))                                                    CRAN1360
      Q(I)=((R+R+R)-RX*AK)+Q(I)                                         CRAN1370
      Y(I)=Y(I)+R                                                       CRAN1380
   29 CONTINUE                                                          CRAN1390
      GO TO (1551, 224, 219, 251),K                                     CRAN1400
  219 RX=1.70710678                                                     CRAN1410
      GO TO 1551                                                        CRAN1420
  251 ASSIGN 34 TO KS                                                   CRAN1430
      GO TO 1551                                                        CRAN1440
  224 ASSIGN 30 TO KS                                                   CRAN1450
      X=XN                                                              CRAN1460
 1551 CALL DERIV                                                        CRAN1470
      IF ( HELP ) GO TO 2020
C     THIS CALL OF DERIV IS DURING R-K ONLY
   36 K=K-1                                                             CRAN1480
      IF(K)18,18,37                                                     CRAN1490
C***** END OF ONE RK STEP                                               ********
C     DELTAX IS DONE.  THE CODING IS A BIT COMPLEX IN ORDER TO MINIMIZE CRAN1510
C     THE LOOP BEGINNING AT   37  IS EXCTD 4 TIMES BEFORE ONE STEP IN   CRAN1500
C     MULTIPLICATIONS AND INDEXING.  IT IS EQUIVALENT TO SLOWER CODE,   CRAN1520
C     AS FOLLOWS... DO 36 J=1,4   WHEREIN J=5-K                         CRAN1530
C                   DO 29 I=1,N+1                                       CRAN1540
C                   AK(I,J)=DELTAX*F(I)                                 CRAN1550
C                   R (I,J)=A(J)*AK(I,J)-B(J)*Q(I)                      CRAN1560
C                   Y (I)  =Y(I)+R(I,J)                                 CRAN1570
C                   Q (I)  =Q(I)+3.* R(I,J)-C(J)*AK(I,J)                CRAN1580
C                29 X= Y(N+1)                                           CRAN1590
C                   CALL DERIV (X,Y,F)                                CRAN1600
C                36 CONTINUE                                          CRAN1610
C                   RETURN                                              CRAN1620
C        ACC. TO S. GILL, CAMB. PHIL. SOC., PROC., 47,P96 (1951), THE   CRAN1630
C     VALUES OF A, B , AND C ARE BEST....                               CRAN1640
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C           A(J)=0.5,1.-SQRTF(.5),1.+SQRTF(.5),1./6.    J=1,4           CRAN1650
C           B(J)=1. ,1.-SQRTF(.5),1.+SQRTF(.5),1./3.    J=1,4           CRAN1660
C           C(J)=0.5,1.-SQRTF(.5),1.+SQRTF(.5),0.5      J=1,4           CRAN1670
C                                                                       CRAN1680
C
C     FOLLOWING IS REACHED FROM STMT 16 WHEN KBC=0, AFTER PRED-CORR     CRAN1690
C     INITIALIZATION IS COMPLETE.                                       CRAN1700
 212  IF ( ENDONX .AND. (XHAT-X)/(4.*H) .LT. 1. ) GO TO 17
      IF ( E(MINUT) .GT. BOUNDA ) GO TO 28
  100 DO 4 I=2,MINUT                                                     CRAN1750
    4 E(1)=E(1)+E(I)                                                    CRAN1760
      IF(E(1)-BOUND)38,28,28                                            CRAN1770
C      28 IS USUAL. 38 IS PREPARE TO DOUBLE DELTAX.                     CRAN1780
   28 DO 39 I=1,N                                                       CRAN1790
      F5(I)=F4(I)                                                       CRAN1800
      F4(I)=F3(I)                                                       CRAN1810
      F3(I)=F2(I)                                                       CRAN1820
      F2(I)=F1(I)                                                       CRAN1830
      F1(I)=F0(I)                                                       CRAN1840
      F0(I)=F (I)                                                       CRAN1850
      Y5(I)=Y4(I)                                                       CRAN1860
      Y4(I)=Y3(I)                                                       CRAN1870
      Y3(I)=Y2(I)
      Y2(I)=Y1(I)
      Y1(I)=Y0(I)                                                       CRAN1900
      Y0(I)=Y (I)                                                       CRAN1910
   39 Y(I)=1.547652*Y(I)+2.017204*Y2(I)-1.867503*Y1(I)-.697353*Y3(I)+S* CRAN1920
     1(.985508124*F(I)+.895121303*F2(I)-.351589071*F3(I)-F1(I))         CRAN1930
   40 X=X+H                                                             CRAN1940
      CALL DERIV                                                        CRAN1950
      IF ( HELP ) GO TO 2030
C     THIS CALL OF DERIV IS FIRST WITH PREDICTED Y VECTOR AND MAY BE
C     REACHED WITH LAST STEP OF AN R-K STEP HENCE UNCHECKED OR WITH
C     LAST STEP A GOOD PC.
   42 DO 10 I=2,MINUT                                                    CRAN1960
   10 E(I-1)=E(I)                                                       CRAN1970
      E(MINUT)=0.                                                        CRAN1980
      DO 43 I=1,N                                                       CRAN1990
      T=Y0(I)+AK*(9.*F(I)+19.*F0(I)+F2(I)-5.*F1(I))                     CRAN2000
      PMC=Y(I)-T                                                        CRAN2010
C       AT THIS POINT, PMC IS PREDICTOR-CORRECTOR                       CRAN2020
      IF ( DONT ) GO TO 43
   72 IF(NB(I))43,44,47                                                 CRAN2040
   44 IF (Y(I))46,43,46                                                 CRAN2050
   46 PMC=PMC/Y(I)                                                      CRAN2060
   47 IF(ABS(PMC)-E(MINUT))43,43,48                                      CRAN2070
   48 E(MINUT)=ABS(PMC)                                                  CRAN2080
   43 Y(I)=T                                                            CRAN2090
C       HERE, E(MINUT) IS THE MAX. TRUNC. ERROR EST., ABS. OR REL., OVER ICRAN2100
C     WHILE THIS REST OF E ARE ITS PREDECESSORS.                        CRAN2110
      IF(E(MINUT)-BOUNDB)50,50,51                                        CRAN2120
   50 GO TO IS,(15,55)                                                  CRAN2130
C      15 IS NORMAL AND CALLS DERIV, JUMPING TO 18 TO STEP INIT+1,RETURNCRAN2140
C      55 IS REACHED FIRST STEP AFTER A SEQUENCE OF RKG STEPS.(CRD 0510)CRAN2150
C      WHEN LARGEST ERROR EXCEEDS BOUND, STMT 51 IS A BRANCH GOVERNED   CRAN2160
C     BY WHETHER THIS IS ON FIRST P-C STEP OR NOT. 52 IS NORMAL.        CRAN2170
 51   IF ( .NOT. OKPC ) GO TO 59
C      52 IS REACHED WHEN LARGEST ERROR EXCEEDS BOUND, FNCTN OF PRECISN.CRAN2190
```

```
   52 X=X-H                                                            CRAN2200
      DO 54 I=1,N                                                      CRAN2210
      Y(I)=Y0(I)                                                       CRAN2220
   54 F(I)=F0(I)                                                       CRAN2230
      ASSIGN 20 TO KT
 53   IF ( DONT ) GO TO 1000
      H=.625*H                                                         CRAN2240
      HELP   = .FALSE.
C     NOTE - ALL STEP SIZE REDUCTIONS GO THRU HERE
C     EXCEPT ON ENDONX INITIATED REDUCTION.
      GO TO 17                                                         CRAN2250
C      RETURN TO 17 SETS UP RKG INITIALIZATION                         CRAN2260
 55   OKPC   = .TRUE.
      ASSIGN 15 TO IS                                                  CRAN2280
      GO TO 15                                                         CRAN2300
C
C     ABOVE SEQUENCE COMPLETES INITIALIZATION OF PRED-CORR ROUTINE.    CRAN2310
C      NEXT,FAILURE OF FIRST TEST AFTER RKG SEQUENCE CAUSES BACKUP 3   CRAN2320
C     STEPS.                                                           CRAN2330
   59 X=X-4.*H                                                         CRAN2340
      DO 60 I=1,N                                                      CRAN2350
      Y(I)=Y3(I)                                                       CRAN2360
   60 F(I)=F3(I)                                                       CRAN2370
 61   ASSIGN 18 TO KT
      GO TO 53                                                         CRAN2380
C      REFER TO CARD 1130 FOR RETURN TO RKG INITIALIZATION.            CRAN2390
C     THE FOLLOWING SETS UP DOUBLING DELTX                             CRAN2400
   38 H=2.*H                                                           CRAN2410
      DO 64 I=1,N                                                      CRAN2420
      F2(I)=F3(I)                                                      CRAN2430
      F3(I)=F5(I)                                                      CRAN2440
      F0(I)=F (I)                                                      CRAN2450
      Y2(I)=Y3(I)                                                      CRAN2460
      Y3(I)=Y5(I)                                                      CRAN2470
   64 Y0(I)=Y(I)                                                       CRAN2480
C       23 IS REACHED AFTER 3 RKG STEPS, I E WHEN KBC=0.(REF. STTMT 22) CRAN2490
   23 AK=.0416666667*H                                                 CRAN2500
      E(MINUT)=10.                                                       CRAN2510
      S=H*2.03169                                                      CRAN2520
      DO 62 I=1,N                                                      CRAN2530
C     SAME AS STATEMENT 39
   62 Y(I)=1.547652*Y(I)+2.017204*Y2(I)-1.867503*Y1(I)-.697353*Y3(I)+S* CRAN2540
     1(.985508124*F(I)+.895121303*F2(I)-.351589071*F3(I)-F1(I))        CRAN2550
      GO TO 40                                                         CRAN2560
C      ABOVE CALLS DERIVATIVE WITH FIRST PREDICTED Y VECTOR.           CRAN2570
C
 2020 K      = 3-KBC
      X      =XN- K*H
      GO TO (2021,2022,2023),K
 2021 DO 2024 I=1,N
      F(I)   = F0(I)
 2024 Y(I)   = Y0(I)
      GO TO 61
 2022 DO 2025 I=1,N
      F(I)   = F1(I)
 2025 Y(I)   = Y1(I)
      GO TO 61
 2023 DO 2026 I=1,N
```

```
      F(I)   = F2(I)
 2026 Y(I)   = Y2(I)
      GO TO 61
C
 2030 IF ( OKPC ) GO TO 52
      GO TO 59
C
 1000 WRITE (2,1001)
 1001 FORMAT ('0THE USE OF A FIXED STEP SIZE (DONT=TRUE) IS INCOMPATIBLE
     . WITH USE OF HELP IN DERIV AND IS GENERALLY USELESS.'/' RUN ABORTE
     .D.')
      CALL EXIT
C
 2000 WRITE (2,2001)
 2001 FORMAT('0 CRANE WAS CALLED WITH INITIAL VALUES UNACCEPTABLE TO DER
     .IV. CASE ABORTED.')
      CALL EXIT
C
 2040 ENDONX = .FALSE.
      WRITE (2,2041)
 2041 FORMAT('0VALUES OF ENDONX, XHAT, X, AND H ARE NOT COMPATIBLE.
     ..  RUN ABORTED.')
      CALL EXIT
      GO TO 2
      END                                                               CRAN2580
```

J.15 SUBROUTINE DERIV

```
      SUBROUTINE DERIV
C      PARAMETER MM=71,M2=MM+2
C  UNIX 8/00, JVI
      PARAMETER (MM=71,M2=MM+2)
      LOGICAL DONT,ENDONX,OKPC,HELP,TRAN
      LOGICAL IPLOP
      DOUBLE PRECISION QVECTS
C
      DIMENSION BF(40)
      DIMENSION QUGIS(10),QISG(10),ACSUTE(10),QOSW(10),QOSA(10),
     $          SUITA(10),QUGG(10)
      DIMENSION TIS(10),TOS(10)
C
      EQUIVALENCE(T(42),TIS(1)),(T(52),TOS(1))
C
      COMMON/METCOM/ MODE,ICOND,INIT,IPURGE,II(10),CURVES,RM,UEFF,AC,AR,
     &       TCAB,TW,VCAB,PCAB,ALUG,AKUG,EUG,WF,TWI,CPW,UAG,
     &       DTIME,TDEWC,TDEW,U,ACSUIT(10),ARSUIT(10),CPG,CFMS,
     &       TGIN,PG,PO2,ALS(10),AKS(10),EIS(10),EOS(10),CPS(10),
     &       QASRB(10),VF,VEFF,WORK,TUGAV,WS(10),C(41),TWO,SQUG,
     &       QEVAP,TOTL,QSHIV,QSTOR,STORAT,SCAB1,CLO,TISAV,WG,
     &       TOSAV,TGOUTS,RMIX,PN2,QLCG(40),QSEN(40),QRAD(40),
     &       TSET(43),EMAX(40),PCFLO(5),G,TUG(10),TGOUT(10),TG(10),
     &       TM(10),WH2OO,WO2OUT,WCO2O,WGOUT,SHSO,PULSE,QR,IPLOP,
     &       TDEWA,SCABC,QRSEN1,QRSEN5,ACE(10),SQUGW,QLAT(40),
     &       WGIN,VOLHMT,HCO2MH,QRSEN2,QRSEN3,QRSEN6,WH2OIN,QRSE15,QD
      COMMON/LCG/ WDOT1,UASB,EL,EL2,DE,WT,CPHX,WTDUCT,CPDUCT,WTDUC2,
     $  ELP,ELP2,DEP,RHOC,WTPIPE,WTPIP2,CPP,SUBKA,UAHXS,WN2
      COMMON/DWC/TIME
      COMMON/TMAT/QVECTS(MM),QVECT(MM),TDIFF,QVECST,
     $       PREC,DONT,HELP,OLDT,H,ENDONX,XHAT,OKPC,TRAN,WGE10,
     $       NCO2,T(M2),NMT,IQ,ICYCLE,IFLG,NB(MM),MINUT,INITL
      COMMON/HUDUNT/ QMET(40),QCOND(40),QCONV(40)
      COMMON /FEEDWA/ FDWTRR
      COMMON/DERSUT/  QUGIS,QISG,ACSUTE,QOSW,QOSA,SUITA,SQOSA,SQOSW,
     $  QUGG
      COMMON/POSTL/ RGAS,PA,CFMC,DENSA,NUMEN,AREAW,VOLCAB,RHOCOA,TATM,
     $ CO2MMH,IQV,CPA,QCNDEN,TOTCON
      COMMON/BLUD/TBF,TSBF,BF,SROR
      COMMON/TSKIN/ TAVSKN, O2RATE, CO2RAT
      COMMON/CHGTGI/ TAVD,TAVD2,TAVP,TAVP2
      SAVE
C
C  T(42-51)-TEMPS  INSIDE THE SUIT, T(52-61)- TEMPS OUTSIDE THE SUIT
C
      HELP=.FALSE.
C
C  IN THE POST LANDING OPTION TCAB AND TW ARE CHANGED WITH TIME, SO
C     THEY MUST BE UPDATED
C
      IF(.NOT. IPLOP) GO TO 10
      TCAB=T(IQV+2)
      IF (TCAB .LT. -459.67) TCAB = -459.67
      TW=T(IQV+3)
      RHOH2O = T(IQV) / VOLCAB
      VPPATN = RHOH2O * 85.76 * (TCAB+460.) / 144.
```

```
      HGMM=760.0/14.7*VPPATN
      TDEWC=DEWPT(HGMM)
      IF (TDEWC .GT. TCAB) TDEWC = TCAB
   10 CONTINUE
C
C  CALCULATE HEAT TRANSFER RATE OF HEAD CORE QVECT(1) AND TRUNK
C  CORE QVECT(5)
C
      QVECT(1)= QMET(1)-QLAT(1)+QCONV(1)-QCOND(1)-QRSEN1
      QVECT(5)= QMET(5)-QLAT(5)+QCONV(5)-QCOND(5)-QRSEN5
C
C  CALCULATE HEAT TRANSFER RATE OF THE REMAINING CORES --ARM(9+13),
C     LEG(17+21),HAND(25+29), AND FOOT(33+37)
C
      DO 1710 I=9,37,4
      QVECT(I)= QMET(I)+QCONV(I)-QCOND(I)
 1710 CONTINUE
C
C  CALCULATE HEAT TRANSFER RATE OF THE MUSCLE--HEAD(2),TRUNK(6),
C    ARM(10+14),LEG(18+22),HAND(26+30),FOOT(34+38)
C
      QVECT(2)= QCOND(1)+QMET(2)-QLAT(2)+QCONV(2)-QCOND(2)-QRSEN2
      QVECT(6)= QCOND(5)+QMET(6)-QLAT(6)+QCONV(6)-QCOND(6)-QRSEN6
      DO 1720 I=10,38,4
      QVECT(I)= QCOND(I-1)+QMET(I)+QCONV(I)-QCOND(I)
 1720 CONTINUE
C
C  CALCULATE HEAT TRANSFER RATE OF THE FAT LAYER --HEAD(3),TRUNK(7),
C     ARM(11+15),LEG(19+23),HAND(27+31),FOOT(35+39)
C
      QVECT(3)= QCOND(2)+QMET(3)-QLAT(3)+QCONV(3)-QCOND(3)-QRSEN3
      DO 1730 I=7,39,4
      QVECT(I)= QCOND(I-1)+QMET(I)+QCONV(I)-QCOND(I)
 1730 CONTINUE
C
C  CALCULATE HEAT TRANSFER RATE OF THE SKIN--HEAD(4),TRUNK(8),
C     ARM(12+16),LEG(20+24),HAND(28+32),FOOT(36+40)
C
      DO 1740 I=4,40,4
      QVECT(I)= QCOND(I-1)+QMET(I)-QLAT(I)+QCONV(I)-QSEN(I)
     $ -QRAD(I)-QLCG(I)
 1740 CONTINUE
C
C  CALCULATE HEAT TRANSFER RATE OF THE CENTRAL BLOOD
C
      SQCONV=0.
      DO 13 I=1,40
      SQCONV=SQCONV-QCONV(I)
   13 CONTINUE
      QVECT(41)=SQCONV
      DO 50 I=1,41
      QVECT(I)=QVECT(I)/C(I)
   50 CONTINUE
      IF(MODE .EQ. 0)GO TO 500
C
C  CALCULATE HEAT TRANSFER RATE INSIDE THE SUIT, QVECT(42-51),
C  AND OUTSIDE THE SUIT QVECT(52-61)
C
```

```
      J=42
      K=52
      DO 100 I=1,10
      IF(I.EQ. 10 .AND. MODE .EQ. 3) GO TO 80
      QVECT(J)=2./WS(I)/CPS(I)*(QUGIS(I)-QISG(I)-ACSUTE(I)/SUITA(I)*
     $   (TIS(I)-TOS(I)))
      QVECT(K)=2./WS(I)/CPS(I)*(ACSUTE(I)/SUITA(I)*(TIS(I)-TOS(I))-
     $   QOSW(I)-QOSA(I))
      GO TO 85
   80 CONTINUE
      QVECT(J)=0.
      QVECT(K)=0.
   85 CONTINUE
      J=J+1
      K=K+1
  100 CONTINUE
      IF(UASB .GT.0)CALL SRTLCG(WF,WDOT1,CPW,UASB,TWO,TWI,CFMS,PG,
     $                         TGOUTS,CPG,RM,SHSO,DTIME,TDEW,TGIN,
     $                         T(62),T(64),T(63),T(65),T(66))
  500 CONTINUE
      IF (.NOT. IPLOP) GO TO 1500
      DENSC=(PCAB-VPP(TDEWC))*144.0/(RGAS*(TCAB+460.0))
      IF (TATM .LT. TDEWA) TDEWA = TATM
      VPPATM=VPP(TDEWA)
      SPHUMA=VPPATM*18.0/((PA-VPPATM)*29.0)
      DENSA=(PA-VPPATM)*144.0/(RGAS*(TATM+460.0))
      WTH2OA=60.*CFMC*DENSA*SPHUMA
      WTH2OG=NUMEN*TOTL/1040.
      VPPCAB=VPP(TDEWC)
      SPHCAB=VPPCAB*18.0/((PCAB-VPPCAB)*29.0)
      WTH2OO=60.*CFMC*DENSC*SPHCAB
      WTCOND=0.0
      IF((VPP(TDEWC)-VPP(TW)).LT.0.0)GO TO 1600
      WTCOND=.126*AREAW*((TCAB+460.)**1.04)*VEFF/100.*SQRT(VCAB/PCAB)*
     $       (VPP(TDEWC)-VPP(TW))
      WTCON1=1.32*AREAW*(TCAB+460.)*(VPP(TDEWC)-VPP(TW))*(PCAB*G*(0.005*
     $       PCAB*ABS(TCAB-TW)+1.02*(VPP(TDEWC)-VPP(TW))))**0.25/PCAB
      IF(WTCON1.GT.WTCOND)WTCOND=WTCON1
      WTCOND=WTCOND/1040.0
      IF( .NOT. TRAN) GO TO 1800
      TOTCON=TOTCON+WTCOND*H
      GO TO 1800
 1600 CONTINUE
      IF(TOTCON .LE. 0 .OR. .NOT. TRAN) GO TO 1800
      WTCOND=.126*AREAW*((TCAB+460.)**1.04)*VEFF/100.*SQRT(VCAB/PCAB)*
     $       (VPP(TW)-VPP(TDEWC))
      WTCON1=1.32*AREAW*(TCAB+460.0)*(VPP(TW)-VPP(TDEWC))*(PCAB*G*(0.005
     $      *PCAB*ABS(TW-TCAB)+1.02*(VPP(TW)-VPP(TDEWC))))**0.25/PCAB
      IF(WTCON1.GT.WTCOND)WTCOND=WTCON1
      WTCOND=WTCOND/1040.0
      IF(TOTCON .LE. WTCOND*H) GO TO 1801
      TOTCON=TOTCON-WTCOND*H
      WTCOND=-WTCOND
      GO TO 1800
 1801 WTCOND=-TOTCON/H
      TOTCON=0.0
 1800 CONTINUE
      QVECT(IQV)= WTH2OA+WTH2OG-WTH2OO-WTCOND
```

```
      CO2IN = CFMC*60.*RHOCOA
      CO2GEN = NUMEN*CO2RAT
      CO2OUT = T(IQV+1)/VOLCAB*CFMC*60.
      QVECT(IQV+1)=CO2IN+CO2GEN-CO2OUT
      PCO2 =(T(IQV+1)/VOLCAB*(TCAB+460.)*35.13)/144.
      CO2MMH= 760./14.7 * PCO2
      QSENT=NUMEN*SCABC
      QCNDEN=WTCOND*1040.
      IF(TCAB.LE.TDEWC)TDEWC=TCAB
      QOUT = CFMC*144.*PCAB*CPA*60./RGAS
      QIN  = CFMC*144.*PCAB*CPA*(TATM+460.)*60./(RGAS*(TCAB+460.))
      QWALL =0.0212*AREAW*SQRT(PCAB*VCAB)*(TW-TCAB)
      QWALL1=0.06  *AREAW*(PCAB**2*G*ABS(TCAB-TW))**0.25*(TW-TCAB)
      IF(ABS(QWALL1).GT.ABS(QWALL))QWALL=QWALL1
      SQUGW3=SQUGW
      IF(MODE .NE. 3) GO TO 1850
      SQUGW3=SQOSW+QUGIS(10)
      QSENT=NUMEN*(TGOUTS-TCAB)*WG*CPG+ SQOSA +QUGG(10)+QRSE15
      QOUT=(CFMC+CFMS)*144.*PCAB*CPA*60./RGAS
 1850 CONTINUE
      QVECT(IQV+2)=(QIN+QSENT+QWALL-QOUT)/(DENSC*VOLCAB*CPA)
      QVECT(IQV+3)=(SQUGW3*NUMEN-QWALL+QCNDEN)/(1.333*VOLCAB*0.214)
 1500 CONTINUE
      RETURN
      END
```

J.16 SUBROUTINE SRTLCG

```
      SUBROUTINE SRTLCG(WDOT,WDOT1,CP,UASB,TSTOUT,TSTIN1,CFMS,PG,
     $                  TGOUTS,CPG,RM,SHSO,DTIME,TDEW,TGIN,THX,
     $                  TDUCT2,TDUCT,TPIPE,TPIPE2)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                          C
C SUBROUTINE SRTLCG SIMULATES THE PORTABLE LIFE SUPPORT SYSTEM (PLSS) OF   C
C THE EXTRAVEHICULAR MOBILITY UNIT.  THE OUTLET FLOW CONDITIONS OF THE     C
C COOLANT FROM THE LIQUID COOLED GARMENT AND THE OXYGEN FROM THE PRESSURE  C
C GARMENT ASSEMBLY, CALCULATED IN SUBROUTINES SUIT OR SHIRT, ARE INPUT.    C
C THIS SUBROUTINE SIMULATES THE HEAT EXCHANGE OF THESE FLUIDS WITH THE     C
C FAN, PUMP, LITHIUM HYDROXIDE BED, DIVERTER VALVE, SUBLIMATOR, PIPES AND  C
C DUCTS OF THE PLSS.  NEW TEMPERATURES OF THE INLET FLUIDS AND THE PLSS    C
C COMPONENTS ARE CALCULATED AND RETURNED TO THE SUIT OR SHIRT SUBROUTINES. C
C                                                                          C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      COMMON/FEEDWA/FDWTRR
      COMMON/GO/UAHX
      COMMON/CHGTGI/TAVD,TAVD2,TAVP,TAVP2
      REAL TSBIN1,TSUBOT
C
      DATA UAHX,EL,EL2,DE,WT,CPHX,WTDUCT,CPDUCT,WTDUC2/3.950,1.915,
     $     1.79,0.0625,6.9,0.11,1.064,0.15,0.995/
      DATA ELP,ELP2,DEP,RHOC,WTPIPE,WTPIP2,CPP,SUBKA
     $     /4.4,4.7,0.0295,62.4,0.1472,0.1849,1.0,500.0/
      DATA UAHXS/112.8/
      DATA TSBIN/75.0/
      DATA TSBOUT,APIPE,APIPE2,H1P,H2P/75.,1.,1.,1.,1./
      SAVE
C
      WDOTBY = WDOT-WDOT1
      WF=WDOT
      CPW=CP
   10 TSBIN1=TSTOUT+27.312/WDOT
      IF(TSBIN1.LE.32.0)TSBIN1=32.1
      IF (UAHX.GT.0.0) GO TO 20
      TSUBOT = EXP(ALOG(TSBIN1-32.)-UASB/WDOT1) + 32.
      TSBOUT = TSUBOT + 70.5/(WDOT1*CP)
      IF (UAHX.LE.0.0) GO TO 30
   20 CONTINUE
      WDOTG=CFMS*PG*144.0*60.0/(48.3*(TGOUTS+459.67))
      ADUCT=EL*3.1416*DE
      ADUCT2=EL2*3.1416*DE
      VL=CFMS / (3.1416*DE**2.0/4.0)    *60.0
      APIPE=ELP*3.1416*DEP
      APIPE2=ELP2*3.1416*DEP
      VLP=WF/((RHOC*3.1416*DEP**2)/4.0)
      VLP2=WF/((RHOC*3.1416*DEP**2)/4.0)
      RHO=PG*144.0/(48.3*(TAVD+459.67))
      RHO2=PG*144.0/(48.3*(TAVD2+459.67))
      H1=0.0154/DE*1.86*(RHO*VL*DE/0.0465*0.707*DE/EL)**(1./3.)
      H2=0.0154/DE*1.86*(RHO2*VL*DE/0.0465*0.707*DE/EL2)**(1./3.)
      H1P=0.344/DEP*1.86*(RHOC*VLP*DEP/2.71*7.88*DEP/ELP)**(1./3.)
      H2P=0.344/DEP*1.86*(RHOC*VLP2*DEP/2.71*7.88*DEP/ELP2)**(1./3.)
      T1=TGOUTS+RM*0.000189*875/(CPG*WDOTG)
      T12=T1-(T1-TDUCT2)*(1.-EXP(-H2*ADUCT2/(WDOTG*CPG)))
      T2=T12-(T12-THX)*(1.-EXP(-UAHX/(WDOTG*CPG)))
```

```
      T3=T2-(T2-TDUCT)*(1.0-EXP(-H1*ADUCT/(WDOTG*CPG)))
      TSBIN=TSTOUT-(TSTOUT-TPIPE)*(1.0-EXP(-H1P*APIPE/(WF*CPW)))
      TSBIN1=TSBIN+27.312/WDOT
      TAVH2O=WDOT1/UAHXS*(TSBIN1-TSUBOT)+THX
      TSUBOT=TSBIN1-(TSBIN1-THX)*(1.0-EXP(-UAHXS/(WDOT1*CPW)))
      WGIHX=SHSO+0.000189*425.0*RM/(WDOTG*1040.0)
      TAVHX=THX-WDOTG*CPG/UAHX*(T2-T12)
      WGOHX=VPP(T2)*18.0/(PG*32.0)
      IF(WF.LE.0.0)TAVH2O=THX
      THX1=DTIME/(WT*CPHX)*(UAHX*(TAVHX-THX)+WDOTG*(WGIHX-WGOHX)
     $     *1040.0+UAHXS*(TAVH2O-THX)-SUBKA*(THX-32.0))+THX
      WGOD=(VPP(T3))*18.0/(PG*32.0)
      TAVD=TDUCT-WDOTG*CPG/(H1*ADUCT)*(T3-T2)
      TAVD2=TDUCT2-WDOTG*CPG/(H2*ADUCT2)*(T12-T1)
      TDUCT1=DTIME/(WTDUCT*CPDUCT)*(H1*ADUCT*(TAVD-TDUCT)
     $       +WDOTG*(WGOHX-WGOD)*1040.0)+TDUCT
      TDUC12=DTIME/(WTDUC2*CPDUCT)*(H2*ADUCT2*(TAVD2-TDUCT2))+TDUCT2
      TDUCT=TDUCT1
      TDUCT2=TDUC12
      THX=THX1
      TDEW=T3
      TGIN=T3
   30 CONTINUE
      TSTIN1=(WDOTBY*(TSBIN1)+WDOT1*TSBOUT)/WDOT
      IF (UAHX.LE.0.0) GO TO 40
      TSBOUT=TSUBOT+70.5/(WDOT1*CPW)
      TSTIN=(WDOTBY*TSBIN1+WDOT1*TSBOUT)/WF
      TSTIN1=TSTIN-(TSTIN-TPIPE2)*(1.0-EXP(-H2P*APIPE2/(WF*CPW)))
      TAVP=TPIPE-WF*CPW/(H1P*APIPE)*(TSBIN-TSTOUT)
      TAVP2=TPIPE2-WF*CPW/(H2P*APIPE2)*(TSTIN1-TSTIN)
      TPIPE1=DTIME/(WTPIPE*CPP)*(H1P*APIPE*(TAVP-TPIPE))+TPIPE
      TPIP12=DTIME/(WTPIP2*CPP)*(H2P*APIPE2*(TAVP2-TPIPE2))+TPIPE2
      TPIPE=TPIPE1
      TPIPE2=TPIP12
      FDWTRR=SUBKA*(THX-32.0)/1040.0
   40 CONTINUE
      RETURN
      END
```

J.17 SUBROUTINE TMATRX

```
      SUBROUTINE TMATRX
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C SUBROUTINE TMATRX IS NOT CURRENTLY BEING USED BY THIS PROGRAM.  AT NEAR  C
C STEADY STATE CONDITIONS OR WHEN dT/dt WAS SMALL, TMATRX WAS USED IN LIEU C
C OF SUBROUTINE CRANE TO SOLVE FOR CREWMAN AND SUIT COMPARTMENT           C
C TEMPERATURES USING A MATRIX INVERSION METHOD.                       C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      PARAMETER (MM=71,M2=MM+2)
      LOGICAL IPLOP
      DIMENSION TSAVE(MM),J2(MM),I2(MM)
      DOUBLE PRECISION A(MM,MM),DELT(MM),X(MM)
      DOUBLE PRECISION QVECTS
C
      COMMON/METCOM/ MODE,ICOND,INIT,IPURGE,II(10),CURVES,RM,UEFF,AC,AR,
     &       TCAB,TW,VCAB,PCAB,ALUG,AKUG,EUG,WF,TWI,CPW,UAG,
     &       DTIME,TDEWC,TDEW,U,ACSUIT(10),ARSUIT(10),CPG,CFMS,
     &       TGIN,PG,PO2,ALS(10),AKS(10),EIS(10),EOS(10),CPS(10),
     &       QASRB(10),VF,VEFF,WORK,TUGAV,WS(10),C(41),TWO,SQUG,
     &       QEVAP,TOTL,QSHIV,QSTOR,STORAT,SCAB1,CLO,TISAV,WG,
     &       TOSAV,TGOUTS,RMIX,PN2,QLCG(40),QSEN(40),QRAD(40),
     &       TSET(43),EMAX(40),PCFLO(5),G,TUG(10),TGOUT(10),TG(10),
     &       TM(10),WH2OO,WO2OUT,WCO2O,WGOUT,SHSO,PULSE,QR,IPLOP,
     &       TDEWA,SCABC,QRSEN1,QRSEN5,ACE(10),SQUGW,QLAT(40),
     &       WGIN,VOLHMT,HCO2MH,QRSEN2,QRSEN3,QRSEN6,WH2OIN,QRSE15,QD
      COMMON/LCG/ WDOT1,UASB,EL,EL2,DE,WT,CPHX,WTDUCT,CPDUCT,WTDUC2,
     $           ELP,ELP2,DEP,RHOC,WTPIPE,WTPIP2,CPP,SUBKA,UAHXS,WN2
      COMMON/POSTL/ RGAS,PA,CFMC,DENSA,NUMEN,AREAW,VOLCAB,RHOCOA,TATM,
     $              CO2MMH,IQV,CPA,QCNDEN
      COMMON/TMAT/QVECTS(MM),QVECT(MM),TDIFF,QVECST,
     $       PREC,DONT,HELP,OLDT,H,ENDONX,XHAT,OKPC,TRAN,WGE10,
     $       NCO2,T(M2),NMT,IQ,ICYCLE,IFLG,NB(MM),MINUT,INITL
      DATA ICNT,DTLNTH,QSLS,DTCL/0,0.,0.,0./
      SAVE
C
C
      IF(IFLG .EQ. 1) GO TO 600
      IF(IQ .NE. -1) GO TO 10
      ICNT=0
      QVECST=0
      DO 20 I=1,NMT
      TSAVE(I)=T(I)
      QVECTS(I)=QVECT(I)
      QVECST=QVECST+QVECTS(I)**2
   20 CONTINUE
      T(1)=T(1)+TDIFF
      IQ=1
      GO TO 999
   10 CONTINUE
      DO 65 I=1,NMT
      A(I,IQ)=(QVECT(I)-QVECTS(I))/TDIFF
   65 CONTINUE
      IF(IQ .EQ. NMT) GO TO 200
      IQ=IQ+1
      T(IQ-1)=TSAVE(IQ-1)
```

```
      T(IQ)=T(IQ)+TDIFF
  999 RETURN
  200 CONTINUE
C
      CALL MINVDP(A,NMT,MM,X,J2,I2)
C
      IQ=-1
      ICYCLE=ICYCLE+1
      DO 310 I=1,NMT
      DELT(I)=0.
      DO 310 J=1,NMT
  310 DELT(I)= -A(I,J)*QVECTS(J) +DELT(I)
      SDELTS=0.
      DO 315 I=1,NMT
      SDELTS=DELT(I)**2+SDELTS
  315 CONTINUE
      DTLNTH=SQRT(SDELTS)
      IF(DTLNTH .LE. 10.) GO TO 540
      DO 520 I=1,NMT
      DELT(I)=(DELT(I)*10.)/DTLNTH
  520 CONTINUE
      DTLNTH=10.
  540 CONTINUE
      DO 325 I=1,NMT
  325 T(I)=TSAVE(I)+DELT(I)
  350 CONTINUE
      IF(.NOT. IPLOP) GO TO 370
      TCAB=T(IQV+2)
      IF (TCAB .LT. -459.67) TCAB = -459.67
      TW=T(IQV+3)
      RHOH2O = T(IQV) / VOLCAB
      VPPATN = RHOH2O * 85.76 * (TCAB+460.) / 144.
      HGMM=760.0/14.7*VPPATN
      TDEWC=DEWPT(HGMM)
      IF (TDEWC .GT. TCAB) TDEWC = TCAB
      GO TO 320
  370 CONTINUE
      IF(MODE .EQ. 0 .OR. UASB .EQ. 0) GO TO 320
      IF(T(62).LT. 32.) T(62)=32.
  320 CONTINUE
C
C     CALCULATE AVERAGE SKIN TEMPERATURE(72) BASED ON PERCENTAGE OF
C     TOTAL SKIN AREA FOR EACH SKIN NODE THAT NODES TEMPERATURE
C
      T(72)=0.07*T(4)+0.3602*T(8)+0.06705*T(12)+0.06705*T(16)+
     $    0.1587*T(20)+0.1587*T(24)+0.025*T(28)+0.025*T(32) +
     $    0.0343*T(36)+0.0343*T(40)
      T(73)=0.02325*T(2)+0.549*T(6)+0.0527*T(10)+0.0527*T(14)+0.1592*
     $    T(18)+0.1592*T(22)+0.00115*T(26)+0.00115*T(30)+0.00115*
     $    T(34)+0.00115*T(38)
      RETURN
  600 CONTINUE
      ICNT=ICNT+1
      IF(ICNT .EQ. 2) GO TO 960
  700 CONTINUE
      QSLS=0.
      DO 950 I=1,NMT
      QSLS=QVECT(I)**2+QSLS
```

```
      DELT(I)=DELT(I)/10.
      T(I)=TSAVE(I)+DELT(I)
  950 CONTINUE
      DTCL=DTLNTH/10.
  955 CONTINUE
      IFLG=0
      GO TO 350
  960 CONTINUE
      QSCUT=0.
      DO 975 I=1,NMT
      QSCUT=QVECT(I)**2+QSCUT
  975 CONTINUE
      CHECK1=.01*(QSLS+99.*QVECST)
      CHECK2=.1*QSLS+.9*QVECST
      IF(QSCUT .GE. CHECK1  .OR.  QSCUT .GE. CHECK2) GO TO 700
      CONLM=-.05*DTLNTH*(100.*QSCUT-QSLS-99.*QVECST)/
     $       (QSLS-10.*QSCUT+9.*QVECST)
      DO 980 I=1,NMT
      DELT(I)=CONLM*DELT(I)/DTCL
      T(I)=TSAVE(I)+DELT(I)
  980 CONTINUE
      GO TO 955
      END
```

J.18 SUBROUTINE MINVDP

```
C           A GENERAL ROUTINE FOR MATRIX INVERSION
C           GAUSS'JORDAN WITH PIVOTING
C           THE OUTPUT INVERSE IS RETURNED IN THE SAME LOCATIONS AS THE
C           ORIGINAL INPUT MATRIX
      SUBROUTINE MINVDP(A,N,NX,X,J2,I2)
      DOUBLE PRECISION A,X,BIGA,DIV  ,E
      DIMENSION A(NX,NX),X(NX),J2(NX),I2(NX)
      DATA I1,J1/0,0/
      M=N
      K=0
      E=0
      I2(1)=0
      J2(1)=0
C*    BEGIN COMPUTATION OF THE INVERSE
      DO 15 L=1,M
      L1=L-1
      BIGA=0.0D0
      DO 5 I=1,M
      DO 1 I3=1,L1
      IF(I-I2(I3))1,5,1
    1 CONTINUE
      DO 4 J=1,M
      DO 2 I3=1,L1
      IF(J-J2(I3))2,4,2
    2 CONTINUE
      IF(BIGA-DABS(A(I,J)))3,3,4
    3 BIGA=DABS(A(I,J))
      J1=J
      I1=I
    4 CONTINUE
    5 CONTINUE
      J2(L)=J1
      I2(L)=I1
      DIV=A(I1,J1)
C*    TEST ELEMENT AGAINST ZERO CRITERION.
      IF(DABS(DIV) .LT. E) K = 1
C*    PERFORM THE COMPUTATIONS
    6 DO 7 J=1,M
      A(I1,J)=A(I1,J)/DIV
    7 CONTINUE
      A(I1,J1)=1.0D0/DIV
      DO 11 I=1,M
      IF(I1-I)8,11,8
    8 DO 10 J=1,M
      IF(J1-J)9,10,9
    9 A(I,J)=A(I,J)-A(I1,J)*A(I,J1)
   10 CONTINUE
   11 CONTINUE
      DO 14 I=1,M
      IF(I1-I) 13,14,13
   13 A(I,J1)=-A(I,J1)*A(I1,J1)
   14 CONTINUE
   15 CONTINUE
C*    COMPUTATION COMPLETE AT THIS POINT
      DO 18 J=1,M
      DO 16 I=1,M
```

```
      I1=I2(I)
      J1=J2(I)
      X(J1)=A(I1,J)
   16 CONTINUE
      DO 17 I=1,M
      A(I,J)=X(I)
 0017 CONTINUE
 0018 CONTINUE
      DO 21 I=1,M
      DO 19 J=1,M
      I1=I2(J)
      J1=J2(J)
      X(I1)=A(I,J1)
 0019 CONTINUE
      DO 20 J=1,M
      A(I,J)=X(J)
   20 CONTINUE
   21 CONTINUE
      RETURN
      END
```

J.19 SUBROUTINE DEWPT

```
      REAL FUNCTION DEWPT ( PMMHG )
C
C *** FUNCTION TO CALCULATE SATURATION TEMPERATURE (DEW POINT)  ***
C *** [DEG F] OF GAS WITH VAPOR PRESSURE "P" [MM HG].           ***
C
      REAL PLOG, PMMHG, PINHG, P, F, G, H, DEWPTR
C
      P = PMMHG * 14.696 / 760.
      IF (P .GE. 0.0185) THEN
         PINHG = P * 2.036
         PLOG = ALOG(PINHG)
         F = -0.00004286517
         G =  0.001626943*PLOG + 0.03533457
         H = -PLOG * (0.07086745*PLOG + 1.) - 2.519124
         DEWPT = (-G + SQRT(G*G - 4.*F*H)) / (2.*F)
      ELSEIF (P .LE. 0.) THEN
         DEWPT = -459.67
      ELSE
         DEWPTR = 0.110516E5 / (20.0455 - ALOG(P))
         DEWPT = DEWPTR - 459.67
      ENDIF
C
      IF (DEWPT .GT. 705.5) DEWPT = 705.5
C
      RETURN
      END
```

J.20 FUNCTION VPP

```
      REAL FUNCTION VPP ( T )
C
C  **  FUNCTION TO CALCULATE SATURATION PRESSURE (PSIA)  **
C  **  AT TEMPERATURE 'T' DEG F.                          **
C
      REAL T, TSAVE, F, G, H
C
      TSAVE = T
C
      IF (T .LE. 0.) THEN
         T = T + 459.67
         IF (T .LE. 0.) THEN
            VPP = 0.
         ELSE
            VPP = EXP (20.0455 - 0.110516E5 / T)
         ENDIF
      ELSEIF (T .GT. 300.) THEN
         T = T + 459.67
         VPP = EXP (15.2670 - 0.839228E4 / T)
      ELSE
C
      F = -0.07086745
      G =  0.001626943*T - 1.0
      H = -0.00004286517*T*T + 0.03533457*T - 2.519124
C
      VPP = 0.4912 * EXP ( (-G - SQRT(G*G - 4.*F*H)) / (2.*F) )
C
      ENDIF
C
      T = TSAVE
C
      RETURN
      END
```

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