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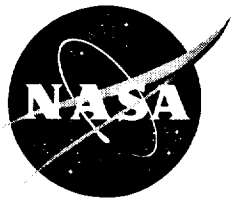

Skin Temperatures During Unaided Egress: Unsuited and While Wearing the NASA Launch and Entry or Advanced Crew Escape Suits

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SUMMARY

Two flight suits are currently worn by crew members during Shuttle launch and landing. The Launch and Entry Suit (LES) and Advanced Crew Escape Suit (ACES) are designed to protect crew members in the case of emergency but may increase thermal stress and limit their egress capabilities. A Liquid Cooling Garment (LCG) worn under the flight suit was designed to counteract the heat storage of the suit.

The purpose of this study was to assess the thermal loads experienced by crew members during a simulated emergency egress before and after spaceflight. Comparisons of skin temperatures were made between the preflight unsuited and suited conditions, between the pre- and postflight suited conditions, and between the two flight suits.

The nineteen subjects of this study were crew members of Space Shuttle missions that participated in pre- and postflight emergency egress simulations. The preflight testing included an unsuited and a suited test consisting of approximately two minutes of rest and then five minutes of walking on a treadmill at 3.5 mph. Within two hours of landing, the postflight testing was conducted similarly to the preflight suited test. Skin temperature was measured at four sites (arm, chest, thigh, and calf) with a mean skin temperature also calculated.

The mean unsuited skin temperature is significantly greater than the mean suited skin temperature during both rest and exercise. The mean skin temperature does not show a difference between the LES and ACES during rest and exercise. During landing, all leads exhibit a decrease in skin temperature at the beginning of deorbit burn and continuing through exit of the Orbiter. Postflight, skin temperature at the central regions of the body (chest and thigh) is higher, while the skin temperature at the peripheral regions (arm and calf) is lower.

We conclude that 1) the LCG provides enough cooling to counteract the thermal stress of the flight suit during rest and landing, 2) the improved suit design of the ACES does not have an impact on the thermal stress during simulated egress, and 3) changes in blood flow distribution during spaceflight may cause the central regions of the body to have higher postflight skin temperature.

GLOSSARY

LES-Launch and Entry Suit
ACES-Advanced Crew Escape Suit
LCG-Liquid Cooling Garment
CTV-Crew Transport Vehicle
D/O Burn-Deorbit Burn
T_{sk}-Skin Temperature
T_{arm}-Arm Skin Temperature
T_{chest}-Chest Skin Temperature
T_{thigh}-Thigh Skin Temperature
T_{calf}-Calf Skin Temperature
T_{mean}-Mean Skin Temperature
TELCS-Thermoelectric Liquid Cooling System

INTRODUCTION

Two spaceflight suits have been developed as a crew protective garment during launch and re-entry of Shuttle missions since the Challenger disaster. The Launch Entry Suit (LES) and Advanced Crew Escape Suit (ACES) are both designed to provide hypobaric protection to astronauts during launch and re-entry, as well as cold water protection in the case of bail-out over water (Barry, 1995). Both suits are used for protection in the case of emergency during the launch and re-entry phases of spaceflight, but may increase the thermal stress and fatigue encountered by the crew members.

The LES is a partial pressure suit that may be worn in flight in the case of emergency to provide protection during any of the following: sudden decrease of cabin pressure, effects of prolonged zero gravity, environmental extremes, interruption of orbiter oxygen supply, and hazardous contaminations in the atmosphere (SCOM, 1996). The LES includes layers of Nomex®, urethane-coated nylon, and a lightweight underwear layer to provide thermal insulation to the astronaut against cold exposure. The suit incorporates a partial anti-g garment, which is worn on the legs and abdomen only, to counteract legward fluid shifts caused by intrathorasic pressure (Chang, 1993). The anti-g garment is composed of a system of bladders which apply pressure directly to the body when inflated (Barry, 1995).

The ACES was developed as a replacement for the LES. Changes were made in the following areas to improve the overall suit design: a simplified design, a minimized coverall weight, reduction of coverall bulk, improvements to aid in self don/doff, and improvements to comfort (Barry, 1995). In addition, the ACES uses a full pressure suit which decreases the overall weight of the suit by combining the restraint and exterior cover layers into a single layer. The full pressure suit is composed of an air tight pressure "balloon" which surrounds the entire body. The design of the suit was further simplified by using Gortex®, a more "breathable" material for the gas container layer, to allow water vapor (perspiration) to pass to the outside while maintaining the internal air pressure (Barry, 1995). The simplification of the suit design increased the comfort level of the suit.

During launch and re-entry, crew members are exposed to cabin and body heat which may raise overall body temperature and produce thermal discomfort. To counteract this discomfort, the LES and ACES both use a liquid cooling garment (LCG) layer beneath the suit to provide cooling to the skin during launch and landing. The LCG is a thermal underwear (Pategonia®)

layer with small plastic tubing woven through the pants and shirt pieces. When the crew members are seated for landing, they connect their LCG to a Thermoelectric Liquid Cooling Unit (TELCU), mounted on the Shuttle seats, which circulates cool water through the garment taking heat away from the body. The heat is removed from the liquid by thermoelectric modules which fan the heat into the Shuttle cabin. The TELCU works in a "buddy system" where two crew members share the same unit. One crew member receives full flow cooling, while the other crew member receives none, with the flow reversed after a few minutes. The cooling can be further adjusted by changing the amount of water that bypasses the heat removal system before recirculation in the LCG. Upon landing, astronauts disconnect themselves from the TELCU to egress to the Crew Transport Vehicle (CTV) where they doff the suit.

In the event of an emergency landing, astronauts are required to stand, move to the hatch, exit the orbiter, and walk/run a distance of 380 meters upwind from the Shuttle. This emergency egress must be performed unassisted in the flight suit with the visor down (Bishop, 1998) and be performed in less than 10 minutes since the individual emergency oxygen supply bottles, which crew members carry on their backpacks, only contain a ten-minute supply of oxygen. It is critical that the LES/ACES does not limit the astronaut's egress capabilities.

Cardiovascular deconditioning caused by exposure to microgravity may cause an individual to respond poorly to a combination of heat stress and reexposure to 1g (Nunneley, 1996). Raised temperatures inside the suit may cause heat strain and prevent a successful egress. Changes in suit temperature are a result of a greater rate of heat storage than cooling capacity. This heat storage may be due to the insulation properties of the suit itself, an increase in metabolic rate, increase in ambient temperature, physiologic responses that occur due to flight and/or landing, or

the metabolic cost of egress. The LCG is designed to counteract these possible increases in heat storage.

DSO 331: Evaluation of Egress Performance is a study currently being conducted to assess egress performance of Space Shuttle crew members after spaceflight. Emergency egress performance is evaluated during a simulated egress in which an astronaut stands and then walks on a treadmill at 3.5 miles per hour for 5 minutes. Preflight testing is conducted in both unsuited and suited conditions. Postflight testing is conducted within two hours of landing in the suited condition only. To partially assess thermal load during the egress simulation, skin temperature is measured at four body locations: upper arm, chest, thigh, and calf.

PURPOSES

The primary purpose of this portion of DSO 331 was to assess the thermal loads experienced by Shuttle crew members during the performance of a simulated egress before and after spaceflight. Specifically, we sought to

- determine the additional heat stress imparted by the LES and ACES suits above normal unsuited conditions
- determine whether there was a differential effect of suit choice (LES or ACES) on thermal stress during simulated egress
- determine whether the LCG would successfully maintain a constant skin temperature from rest through the end of simulated emergency egress
- assess any changes in thermal stress during egress from pre- to postflight

- document skin temperature during deorbit burn, landing, and hatch opening immediately prior to egress

HYPOTHESES

Based on the comparisons made with this skin temperature data, we expect to find the following:

- skin temperature and thermal stress will be higher at all locations in the suited condition than in the unsuited condition
- skin temperature and thermal stress will not be different due to suit choice (LES or ACES)
- liquid cooling combined with the suit will maintain a constant skin temperature during rest, but during the simulated egress exercise, there may be an increase in skin temperature
- postflight skin temperatures will be higher than preflight temperatures indicating possible thermal stress caused by the effects of spaceflight
- the highest skin temperatures at all skin measurement sites during landing will occur shortly after the crew members disconnect from the orbiter cooling to exit the orbiter

METHODS

Overall

Data in this report are a subset from a larger investigation, DSO 331: Evaluation of Egress Performance, and should be considered as preliminary. These data will be reported in full at the completion of that investigation.

The nineteen subjects (17 males, 2 females) in this investigation were crew members participating in Space Shuttle flights of 3 to 15 days. One crew member is included in the data set twice, from two separate flights, to give a total of 20 available data sets. Each testing condition was considered to be a separate data set, with each comparison having a different number of data sets available. Crew members were tested twice: once 3 to 6 months prior to flight and once within 2 hours of landing. During the preflight testing, crew members were tested in both the unsuited (T-shirt and shorts) and suited (LES, n=; or ACES, n=14) conditions. On landing day (R+0), crew members were tested in the suited condition only. All subjects read and signed a statement of informed consent prior to participating in any data collection. The protocol for this study was approved by the JSC Institutional Review Board.

Crew members were instrumented similarly for all tests. Skin temperature was monitored at four sites (upper arm, chest, thigh, and calf) using thermistors (400 Series, Model 409B, Yellow Springs Instruments Co., Inc., Yellow Springs, OH) and recorded in 15-second intervals using data loggers (HOBO XT Temperature Logger, Onset Computer Corporation, Pocasset, MA). Skin thermistors were calibrated, using a water bath before or after testing, by comparing their readings to a certified mercury thermometer. Heart rate was monitored and recorded at 15-second intervals, using a heart watch (Polar Vantage XL, Port Washington, NY) previously validated in our laboratory (Moore, 1997). Inspired and expired respiratory oxygen and carbon dioxide were also measured by indirect calorimetry (TEEM 100, Aerosport, Inc.) and subjects were instrumented for segmental motion analysis. This data will be reported in the final report.

Preflight Testing

Crew members reported to the laboratory in shorts and a T-shirt. Subjects received a complete briefing by the principal investigator on the methods to be employed in this investigation. After the briefing, crew members donned the skin temperature and heart rate monitors and received training as to how to don this hardware prior to landing. Crew members then donned flight boots and were instrumented for motion analysis and metabolic gas collection.

Unsuited Condition

In the first testing session, crew members performed the simulated unaided egress in the unsuited condition while wearing T-shirt, shorts, and flight boots. Subjects stood in the center of the treadmill for approximately two minutes and donned the mouthpiece, pneumotach and nose clips for the sampling of respiratory gases. Then, treadmill speed was increased to 3.5 miles per hour. Upon reaching 3.5 mph, the test began and the heart rate monitor was started. Subjects walked for five minutes at this speed.

Suited Condition

After unsuited testing was completed, crew members donned either the LES or ACES, depending on which suit they would use for flight, and repeated the above test. With the crew member seated in a chair on the treadmill, the g-suit was inflated to the pressure anticipated to be used during landing and egress and the crew member regulated the flow rate to the liquid cooling garment to maintain comfort. With the helmet visor closed, the crew member prebreathed 100% O_2 for six minutes. The crew member then stood, liquid cooling was discontinued, and he/she began walking as the treadmill speed was increased to 3.5 mph. Test time started when the

treadmill speed reached 3.5 mph, at which time the heart watch was started. The crew member continued walking at this speed until one of the following test termination criteria were attained: (1) subject request, (2) completion of five-minute walk, (3) inspired CO_2 exceeded 6%, (4) medical monitor request, or (5) subject exhibited symptoms of CO_2 toxicity (ie., unsteady gait).

Postflight Testing

While in orbit, crew members donned the skin temperature thermistors and the chest strap for the heart rate monitor. Crew members then donned their liquid cooling garments and either the LES or ACES. All crew members received self-controlled liquid cooling during re-entry and landing.

Skin temperature data loggers recorded data in 15-second intervals for seven hours and 30 minutes prior to the completion of the simulated egress after landing. Time of major events, deorbit burn, landing, and hatch opening, were identified from Shuttle operations records. Data from these time points were collated and compared.

All postflight tests were conducted on the Crew Transport Vehicle (CTV) within two hours of landing. Crew members exited the Space Shuttle and were directed to the testing area at the rear of the CTV. Prior to testing, crew members self-adjusted cooling through the liquid cooling garment to personal comfort. Postflight testing was conducted in the same manner as the preflight suited condition, and the same termination criteria were applied. If on R+0 the crew member chose to use a g-suit inflation pressure different from that used during preflight testing, the preflight suited testing condition was repeated 3 to 6 months after landing, and these data were substituted for the preflight data.

Data Reduction and Analysis

For each subject, data for each temperature sensor were time synchronized with all measurement sites and with the HR and metabolic data for each testing condition. Based upon calibration regression equations for each thermistor, the data from five minutes pretest until the end of each treadmill test were aligned for comparative purposes. In the case of data logger malfunctioning, if all but one of the measurement sites were complete, mean substitution was used for one site. The mean of the measurement sites was determined by a weighted equation by Ramanathan (1964). Mean T_{sk} is equal to $(T_{arm} * 0.03) + (T_{chest} * 0.03) + (T_{thigh} * 0.02) + (T_{calf} * 0.02)$.

For the comparison of the preflight unsuited vs. suited conditions, 17 complete data sets were available. The mean and standard error (SE) of the preflight unsuited and suited skin temperature measurements were graphed against time from five minutes pretest until the completion of the test. Analysis of variance was used to determine differences between the conditions and differences between the rest and exercise phases of the test. All analyses were completed using STATISTICA for the Macintosh (Statsoft, Inc., Tulsa, OK), and statistical significance was accepted at P=0.05. All values are reported as mean ± (SE) unless otherwise noted.

For the comparison of the flight suits (ACES vs. LES), the preflight suited data was used, with 17 complete data sets available. Each suited condition mean skin temperature was plotted against time and differences in skin temperature between the suits and from rest to exercise were determined by analysis of variance.

Landing event times for each flight were determined. Data from one minute before to one minute after each event were averaged and accepted as the skin temperature for that event.

Fourteen complete data sets were available to compare skin temperature during landing events. The mean and SE of each skin temperature were graphed against the events to determine a pattern during the landing events.

For the comparison of the preflight vs. postflight data, 15 data sets were available. The mean and SE of each skin temperature were graphed against time, and analysis of variance was used to determine differences in skin temperature caused by spaceflight.

RESULTS

Preflight Unsuited vs. Suited Condition (Table 1, Figure 1)

To assess the additional heat stress imparted by the LES or ACES ensemble, we compared skin temperatures in the suited vs. unsuited conditions. In the unsuited condition, T_{arm} during minute 2-5 of exercise was significantly lower than at rest. T_{thigh} during exercise was significantly lower than at rest. T_{chest} and T_{calf} during exercise were not significantly different than at rest. The mean skin temperature during minute 2-5 of exercise was significantly lower than at rest.

In the suited condition, T_{arm}, T_{thigh}, and mean T_{sk} were significantly higher during exercise than at rest. T_{chest} was significantly higher during minute 2-5 of exercise than at rest. The suited T_{calf} increases during exercise and is significantly different from rest by minute 2.

During both rest and exercise, T_{arm} and T_{calf} were significantly higher suited than unsuited. T_{chest} is significantly lower suited than unsuited during rest. At minute 3 of exercise, suited T_{chest} becomes significantly greater than the unsuited condition. Suited T_{thigh} was significantly higher than unsuited during exercise. In the overall comparison of mean T_{sk}, the suited T_{sk} is significantly greater than the unsuited condition during both rest and exercise.

ACES vs. LES (Table 2, Figure 2)

In the comparison of LES (n=4) and ACES (n=10), there is no significant difference between the two suits at the arm, chest, and thigh measurement sites, or in the mean skin temperature. ACES T_{calf} is significantly lower than LES T_{calf} during rest and through minute 2 of exercise.

Both suits demonstrate a significant rise in skin temperature from rest to exercise, starting at minute 2, at the arm, chest, thigh, and mean skin temperature. ACES T_{calf} is also significantly greater than rest starting at minute 2 of exercise. LES T_{calf} during exercise is not different from T_{calf} at rest.

Landing (Table 4, Figure 4)

A comparison was also made for the skin temperatures at four stages of landing. Skin temperatures were compared at deorbit (D/O) burn, landing/wheel stop, hatch opening, and orbiter exit. From D/O burn through Orbiter exit, all regions dropped in skin temperature. The arm and chest regions demonstrated the highest temperature from D/O burn through orbiter exit. Arm and chest skin temperatures began at 34.04 ± 0.54 and 34.07 ± 0.79 °C at D/O burn and dropped to 33.66 ± 0.28 and 33.55 ± 0.66 °C, respectively, at orbiter exit. The calf skin temperature was the lowest at D/O burn (32.85 ± 0.64 °C), while the thigh skin temperature was the lowest at landing through orbiter exit (32.04 ± 0.45 °C to 31.79 ± 0.35 °C). The mean skin temperature dropped from 33.61 ± 0.59 °C at D/O burn to 32.99 ± 0.39 °C at orbiter exit.

Preflight vs. Postflight Conditions (Table 3, Figure 3)

Comparisons were also made between preflight and postflight suited conditions. At the arm, postflight skin temperatures are significantly lower than preflight skin temperatures in both rest and exercise. During minute 2-5 of exercise, the preflight skin temperature is significantly greater than during rest. Skin temperature at the chest is significantly higher postflight than preflight in both rest and exercise. During minute 4-5 of exercise, preflight chest skin temperature is significantly greater than rest. The thigh shows no difference between preflight and postflight in rest and exercise, and by minute 3, thigh skin temperature during exercise is significantly greater than during rest. Postflight skin temperatures at the calf are significantly lower than preflight only during minutes 2-5 of exercise. Calf preflight skin temperatures are significantly higher than at rest from minute 3-5, while postflight skin temperatures are significantly higher than rest only at minute 5. The mean skin temperature comparison between preflight and postflight conditions shows that postflight mean T_{sk} are significantly higher than preflight in rest and minute 1-2 of exercise. The preflight condition shows minute 3-5 of exercise significantly higher in skin temperature than during rest.

Table 1. Preflight Unsuited vs. Suited Skin Temperatures (Mean ± SE)

Time (min.)	Arm-unsuited (°C)	Chest-unsuited (°C)	Thigh-unsuited (°C)	Calf-unsuited (°C)	Mean - unsuited (°C)	Arm-suited (°C)	Chest-suited (°C)	Thigh-suited (°C)	Calf-suited (°C)	Mean - suited (°C)
-5	31.28 ± 0.39	32.07 ± 0.33	31.14 ± 0.28	31.27 ± 0.24	31.49 ± 0.28	32.04 ± 0.58	31.60 ± 0.76	31.20 ± 0.66	32.06 ± 0.69	31.68 + 0.55
-4	31.22 ± 0.40	32.07 ± 0.33	31.16 ± 0.29	31.25 ± 0.24	31.47 ± 0.28	31.94 ± 0.60	31.54 ± 0.78	31.12 ± 0.70	31.97 ± 0.712	31.60 ± 0.57
-3	31.12 ± 0.41	32.04 ± 0.34	31.15 ± 0.29	31.24 ± 0.24	31.43 ± 0.29	31.83 ± 0.61	31.51 ± 0.79	31.02 ± 0.72	31.90 ± 0.71	31.53 ± 0.58
-2	31.01 ± 0.41	32.07 ± 0.34	31.12 ± 0.30	31.20 ± 0.25	31.39 ± 0.29	31.97 ± 0.57	31.58 ± 0.78	31.09 ± 0.71	31.89 ± 0.69	31.60 ± 0.58
-1	30.95 ± 0.41	32.03 ± 0.34	31.05 ± 0.30	31.09 ± 0.27	31.32 ± 0.29	32.08 ± 0.57 *	31.65 ± 0.78 *	31.26 ± 0.68	32.03 ± 0.65 *	31.72 ± 0.57 *
1	30.85 ± 0.41	31.98 ± 0.35	30.79 ± 0.32 +	30.92 ± 0.32	31.19 ± 0.31	32.25 ± 0.55 *	31.82 ± 0.73	31.49 ± 0.63*+	32.38 ± 0.59 *	31.93 ± 0.53*+
2	30.77 ± 0.40 +	31.94 ± 0.36	30.63 ± 0.32 +	30.84 ± 0.31	31.11 ± 0.30 +	32.42 ± 0.53 *	32.00 ± 0.69 +	31.70 ± 0.59*+	32.76 ± 0.54*+	32.15 ± 0.49*+
3	30.70 ± 0.39 +	31.92 ± 0.35	30.55 ± 0.33 +	30.94 ± 0.31	31.08 ± 0.30 +	32.65 ± 0.49 *	32.18 ± 0.65*+	31.94 ± 0.56*+	33.24 ± 0.49*+	32.42 ± 0.45*+
4	30.66 ± 0.39 +	31.90 ± 0.36	30.53 ± 0.33 +	31.09 ± 0.31	31.09 ± 0.30 +	32.87 ± 0.47 *	32.39 ± 0.62*+	32.21 ± 0.54*+	33.76 ± 0.43*+	32.72 ± 0.43*+
5	30.61 ± 0.39 +	31.88 ± 0.36	30.55 ± 0.33 +	31.30 ± 0.33	31.12 ± 0.30 +	33.07 ± 0.48 *	32.66 ± 0.62*+	32.68 ± 0.52*+	34.39 ± 0.38*+	33.10 ± 0.43*+

\+ Significantly different from rest (assumed at minute -1)

* Significantly different from the unsuited condition

Table 2. ACES vs. LES (Mean ± SE)

Time (min.)	Arm-ACES (°C)	Chest-ACES (°C)	Thigh-ACES (°C)	Calf-ACES (°C)	Mean - ACES (°C)	Arm-LES (°C)	Chest-LES (°C)	Thigh-LES (°C)	Calf-LES (°C)	Mean - LES (°C)
-5	32.25 ± 0.66	31.55 ± 0.83	30.72 ± 0.87	31.47 ± 0.91	31.35 ± 0.69	31.55 ± 1.29	31.72 ± 1.79	32.36 ± 0.70	33.48 ± 0.57	31.94 ± 0.95
-4	32.17 ± 0.69	31.51 ± 0.86	30.59 ± 0.91	31.35 ± 0.93	31.25 ± 0.72	31.40 ± 1.30	31.62 ± 1.83	32.37 ± 0.75	33.47 ± 0.60	31.86 ± 0.96
-3	32.03 ± 0.73	31.47 ± 0.90	30.45 ± 0.94	31.25 ± 0.92	31.14 ± 0.75	31.35 ± 1.24	31.62 ± 1.77	32.39 ± 0.78	33.46 ± 0.59	31.87 ± 0.93
-2	32.22 ± 0.66	31.52 ± 0.91	30.48 ± 0.92	31.25 ± 0.90	31.22 ± 0.75	31.37 ± 1.21	31.70 ± 1.68	32.54 ± 0.74	33.43 ± 0.58	31.92 ± 0.89
-1	32.31 ± 0.66	31.55 ± 0.92	30.67 ± 0.88	31.43 ± 0.85 *	31.33 ± 0.74	31.53 ± 1.17	31.88 ± 1.60	32.68 ± 0.73	33.45 ± 0.55	32.07 ± 0.86
1	32.46 ± 0.66	31.68 ± 0.87	30.95 ± 0.82	31.85 ± 0.77 *	31.57 ± 0.69	31.75 ± 1.09	32.18 ± 1.50	32.77 ± 0.69	33.63 ± 0.50	32.25 ± 0.77
2	32.63 ± 0.63 +	31.85 ± 0.81 +	31.22 ± 0.77 +	32.33 ± 0.71*+	31.83 ± 0.65 +	31.92 ± 1.04 +	32.38 ± 1.43 +	32.87 ± 0.65 +	33.77 ± 0.47	32.40 ± 0.71 +
3	32.84 ± 0.58 +	32.01 ± 0.75 +	31.49 ± 0.73 +	32.90 ± 0.64 +	32.13 ± 0.60 +	32.19 ± 1.02 +	32.60 ± 1.38 +	33.02 ± 0.62 +	34.06 ± 0.48	32.65 ± 0.67 +
4	33.06 ± 0.54 +	32.21 ± 0.71 +	31.79 ± 0.70 +	33.50 ± 0.57 +	32.45 ± 0.55 +	32.42 ± 1.01 +	32.83 ±1.34 +	33.23 ± 0.63 +	34.38 ± 0.49	32.93 ± 0.68 +
5	33.31 ± 0.55 +	32.50 ± 0.71 +	32.33 ± 0.69 +	34.25 ± 0.51 +	32.86 ± 0.56 +	32.56 ± 1.00 +	33.01 ± 1.31 +	33.44 ± 0.64 +	34.70 ± 0.50	33.19 ± 0.70 +

\+ Significantly different from rest (assumed at minute -1)

* Significantly different from LES

Table 3. Preflight vs. Postflight Suited Conditions (Mean ± SE)

Time (min.)	Arm-preflight (°C)	Chest-preflight (°C)	Thigh-preflight (°C)	Calf-preflight (°C)	Mean - preflight (°C)	Arm-postflight (°C)	Chest-postflight (°C)	Thigh-postflight (°C)	Calf-postflight (°C)	Mean - postflight (°C)
-5	32.50 ± 0.58	31.20 ± 0.82	31.02 ± 0.81	32.69 ± 0.72	31.78 ± 0.58	31.74 ± 1.15	33.70 ± 0.46	31.69 ± 0.48	32.23 ± 0.83	32.62 ± 0.55
-4	32.45 ± 0.60	31.13 ± 0.85	30.93 ± 0.84	32.66 ± 0.72	31.72 ± 0.60	31.69 ± 1.16	33.72 ± 0.45	31.68 ± 0.48	32.22 ± 0.82	32.61 ± 0.55
-3	32.42 ± 0.59	31.05 + 0.87	30.79 ± 0.87	32.56 ± 0.73	31.64 ± 0.63	31.65 ± 1.17	33.75 ± 0.45	31.65 ± 0.49	32.24 ± 0.82	32.60 ± 0.56
-2	32.41 ± 0.58	31.06 ± 0.87	30.73 ± 0.89	32.52 ± 0.73	31.63 ± 0.64	31.67 ± 1.17	33.75 ± 0.44	31.67 ± 0.51	32.26 ± 0.82	32.60 ± 0.56
-1	32.47 ±0.58	31.11 ± 0.87	30.83 ± 0.89	32.64 ± 0.72	31.71 0.64±	31.71 ± 1.17 *	33.75 ± 0.44 *	31.71 ± 0.51	32.28 ± 0.82	32.62 ± 0.57 *
1	32.67 ± 0.56	31.31 ± 0.83	31.04 ± 0.86	32.98 ± 0.68	31.93 ± 0.60	31.77 ± 1.17 *	33.75 ± 0.43 *	31.79 ± 0.49	32.33 ± 0.82	32.65 ± 0.56 *
2	32.79 ± 0.54 +	31.51 ± 0.77	31.24 ± 0.84	33.33 ± 0.65	32.13 ± 0.56	31.81 ± 1.17 *	33.78 ± 0.43 *	31.89 ± 0.47	32.44 ± 0.82 *	32.71 ± 0.55 *
3	32.99 ± 0.51 +	31.73 ± 0.73	31.46 ± 0.83 +	33.78 ± 0.63 +	32.39 ± 0.54 +	31.89 ± 1.16 *	33.77 ± 0.41 *	32.04 ± 0.44 +	32.64 ± 0.84 *	32.79 ± 0.54
4	33.23 ± 0.50 +	31.95 ± 0.69 +	31.70 ± 0.83 +	34.28 ± 0.60 +	32.69 ± 0.51 +	31.83 ± 1.24 *	33.75 ± 0.41 *	32.13 ± 0.44 +	32.72 ± 0.91 *	32.81 ± 0.57
5	33.43 ± 0.52 +	32.21 ± 0.69 +	31.95 ± 0.90 +	34.92 ± 0.56 +	33.05 ± 0.53 +	31.44 ± 1.56 *	33.65 ± 0.47 *	32.29 ± 0.51 +	32.77 ± 1.17*+	32.74 ± 0.72

\+ Significantly different from rest (assumed at minute -1)

* Significantly different from preflight

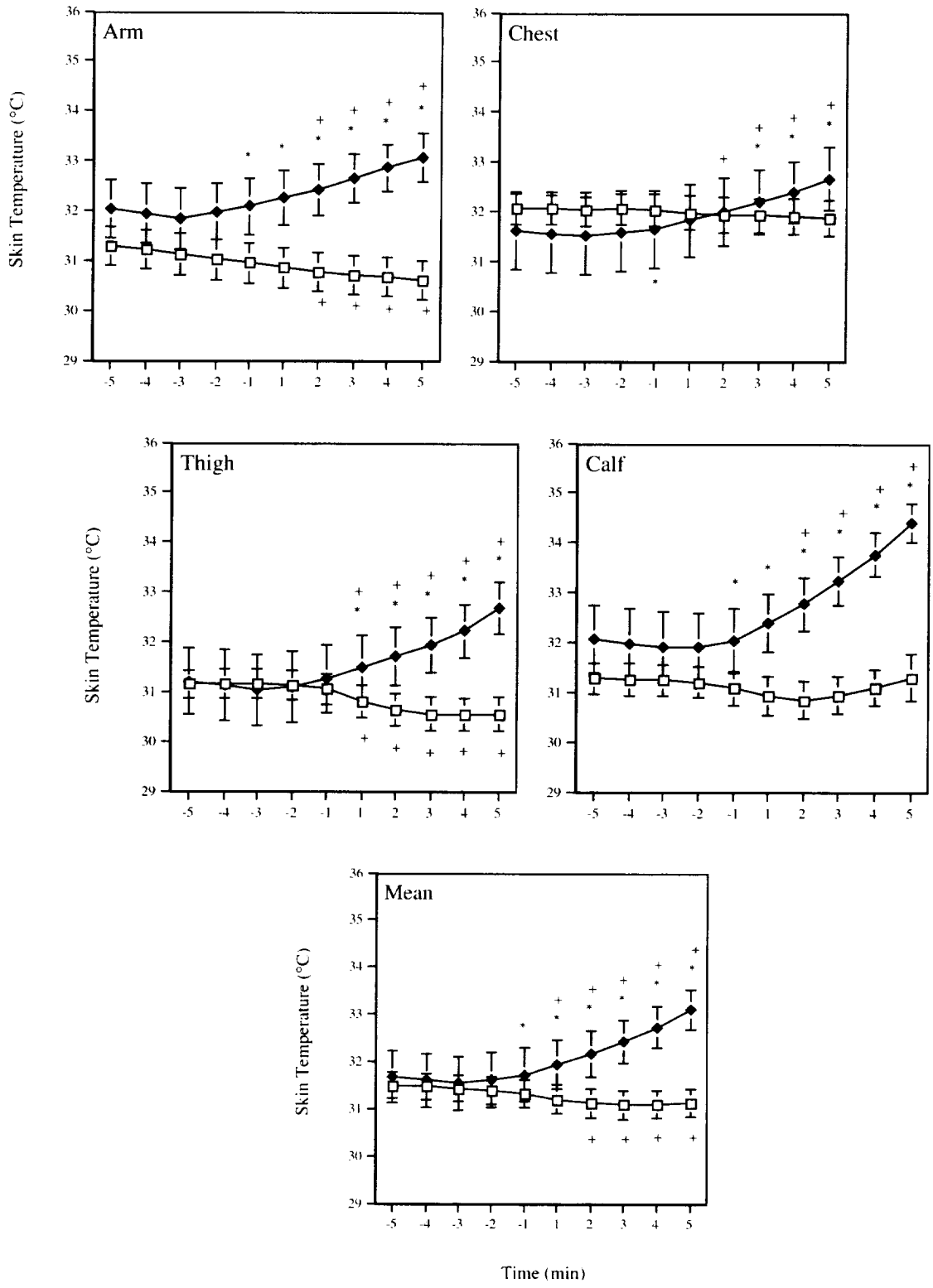

Figure 1. Preflight unsuited vs. suited skin temperature: Unsuited (□), suited (♦), significantly different from unsuited (*), significantly different from rest. (+).

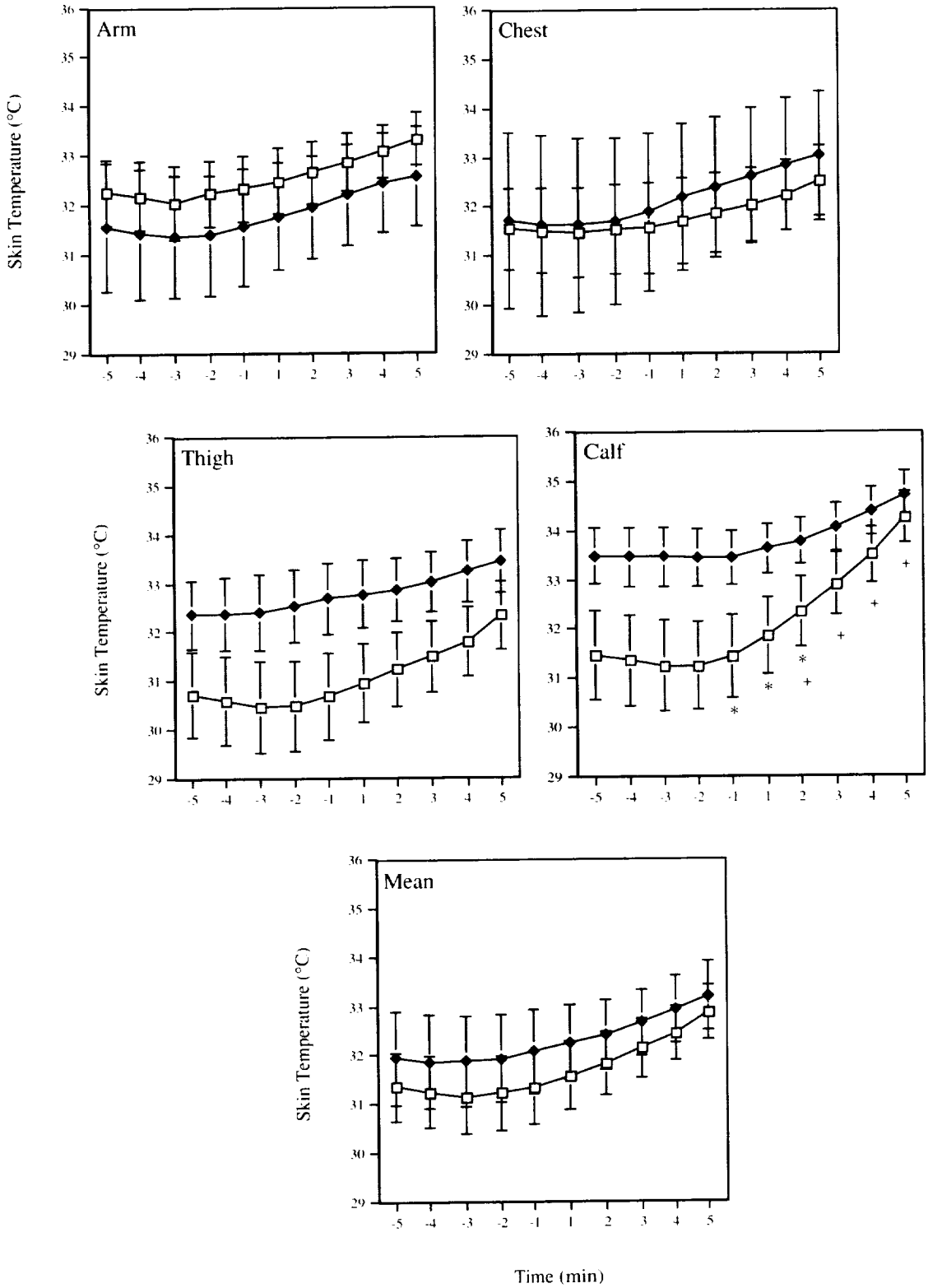

Figure 2. ACES vs. LES. ACES condition (□), LES condition (♦), significantly different from LES (*), significantly different from rest (+).

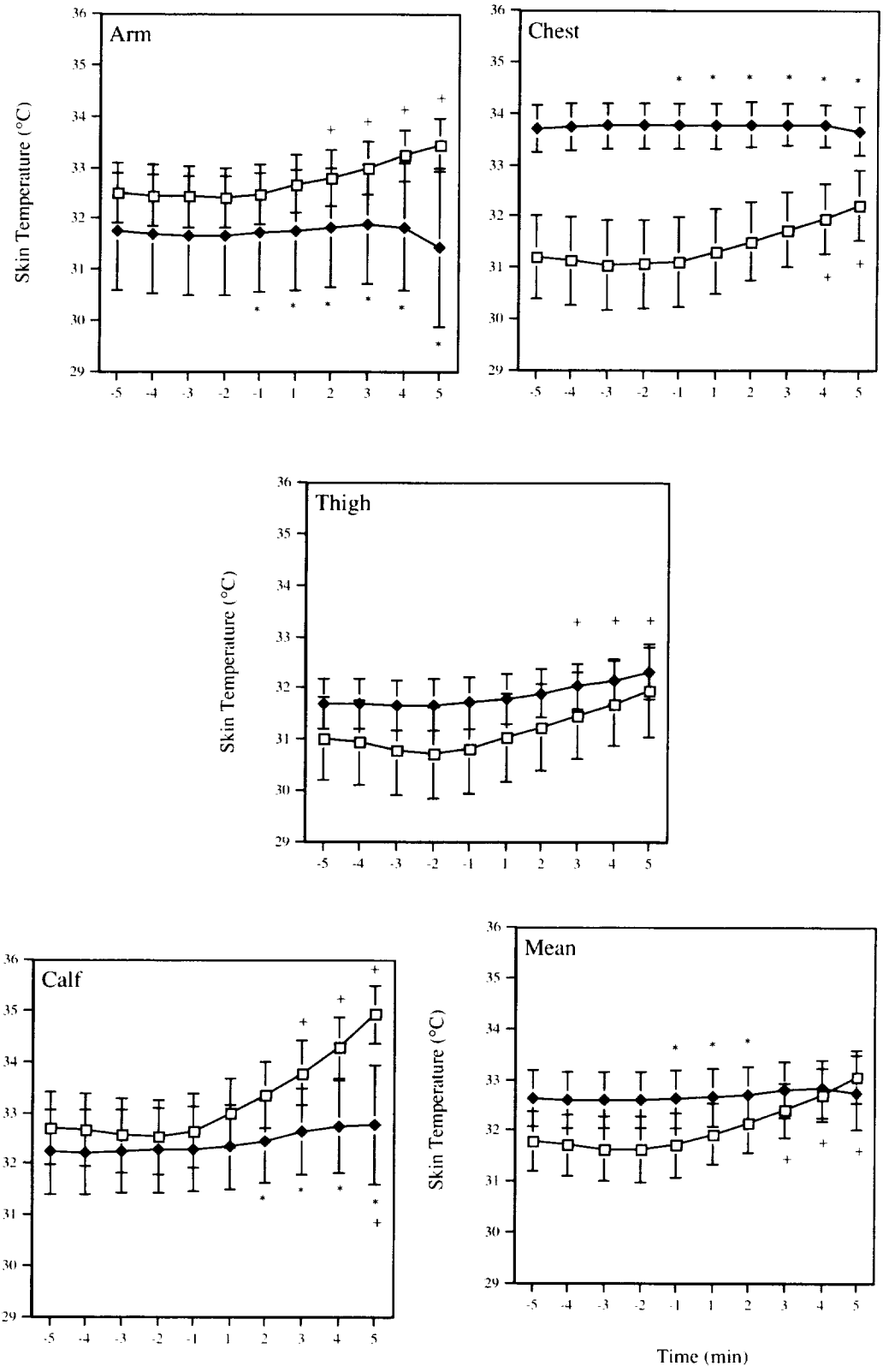

Figure 3. Preflight vs. postflight in the suited condition: preflight (□), postflight (♦), significantly different from preflight (*), significantly different from rest (+).

Table 4. Landing Events (Mean ± SE)

Event	Location Arm (°C)	Chest (°C)	Thigh (°C)	Calf (°C)	Mean (°C)
Deorbit Burn	34.04 ± 0.54	34.07 ± 0.79	33.04 ± 0.52	32.85 ± 0.64	33.61 ± 0.59
Wheel Stop	33.67 ±0.35	34.05 ± 0.66	32.04 ± 0.45	32.65 ± 0.54	33.25 ± 0.44
Hatch Open	33.72 ± 0.30	33.81 ± 0.64	31.87 ± 0.38	32.62 ± 0.53	33.16 ±0.39
Exit Orbitor	33.66 ± 0.28	33.55 ± 0.66	31.79 ±0.35	32.33 ± 0.57	32.99 ±0.39

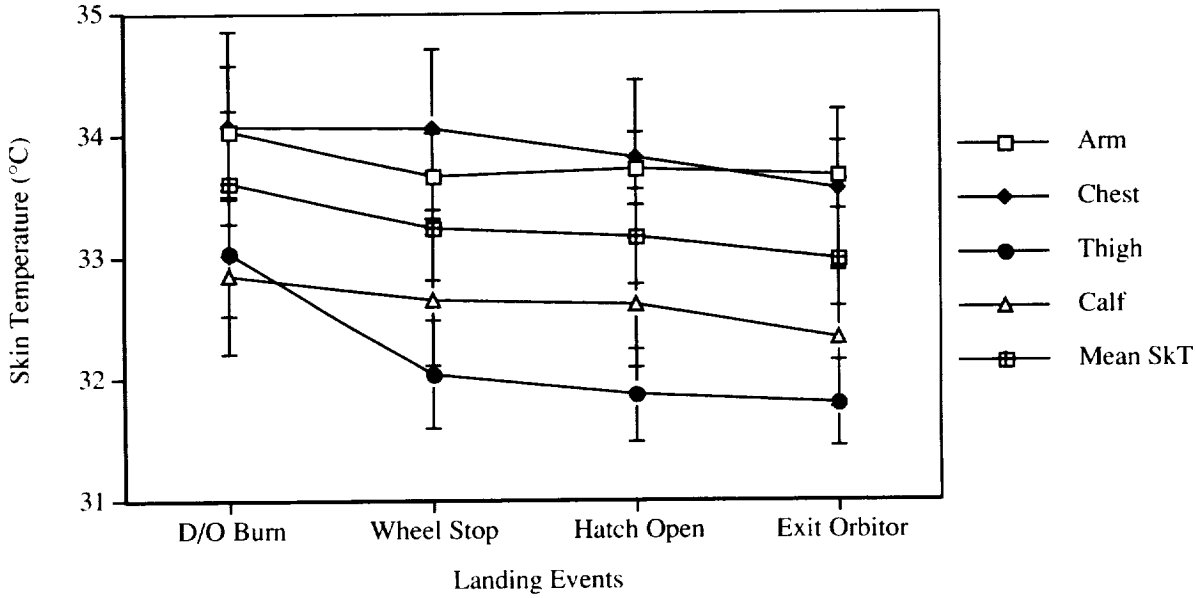

Figure 4. Skin temperature during landing events while wearing the LES or ACES.

DISCUSSION

This investigation provided findings in four specific areas. First, it was determined that the skin temperature in the preflight suited condition is significantly higher than the preflight unsuited condition. Second, during both rest and exercise, there is no significant difference in skin temperature when comparing the two flight suits. Third, it was demonstrated that skin temperature at all body regions evaluated drops continuously from D/O burn to exiting the orbiter. Fourth, it was determined that the skin temperature at the more central body regions

(chest and thigh) are higher postflight, while the peripheral body regions (arm and calf) exhibit a lowered skin temperature postflight.

Unsuited vs. Suited

The first purpose of this paper was to determine the additional heat stress imparted by the flight suits (LES and ACES) when compared to normal unsuited conditions. During both rest and exercise, the preflight suited condition shows a significantly higher skin temperature than the unsuited condition. Skin temperatures are close during rest (31.32 °C unsuited, and 31.72 °C suited), but diverge during exercise. While the unsuited skin temperature drops slightly during exercise, the suited skin temperature rises. Despite the liquid cooling garment, all regions demonstrated a higher skin temperature in the suited condition after the onset of exercise. This result indicates that the LCG provides enough cooling to counteract the flight suit during rest, but upon disconnection from the cooling system prior to egress, does not prevent a rise in skin temperature during five minutes of exercise.

LES vs. ACES

We sought to determine whether there was a differential effect of suit choice (LES or ACES) on additional thermal stress and whether the liquid cooling garment would be successful in maintaining a constant skin temperature from a resting condition through the end of the simulated emergency egress. In a comparison of the two flight suits, the mean skin temperature was not different between the LES and the ACES. Both flight suits allow an increase in skin temperature at the onset of exercise, becoming significantly different from the resting condition

at the second minute. All increases in skin temperature were moderate, with the highest (T_{calf}, minute 5) reaching 34.70 ± 0.50 °C. The ACES has an improved suit design with respect to comfort, but does not appear to cause a significant difference in the prevention of subject overheating during simulated egress.

Landing

The third purpose of this study was to document skin temperature during D/O burn, landing, and hatch opening immediately prior to egress. During the landing process, all measurement sites indicate a trend towards a decrease in skin temperature. The LCG is activated prior to D/O Burn and continues to cool the crew members throughout the landing process. The LCG is then disconnected from the Shuttle cooling unit sometime after the hatch is opened and before the crew members exit the orbiter. The use of the LCG may explain the drop in skin temperature during the landing process. Since skin temperature at all locations does not rise, it can be determined that the LCG successfully prevents a rise in skin temperature during landing.

Preflight vs. Postflight

The fourth purpose of this study was to assess any changes in thermal stress during egress from pre- to postflight. Postflight skin temperature at the central regions of the body (the chest and thigh) are higher, while peripheral regions of the body (the arm and calf) exhibit lowered skin temperatures at postflight testing. This greater regional variability in skin temperature may be related to changes in blood volume and/or blood distribution that occur during spaceflight. There is a 10-15% decrease in blood volume during spaceflight (Buckey et al., 1996), which may

result in a greater peripheral vasoconstriction and a redistribution of blood from the limbs to the thoracic cavity. In a study by Buckey et al. (1996), finishers of an orthostatic tolerance test exhibited a postflight, total peripheral resistance that was significantly greater than preflight. The constricted blood flow to the periphery may cause these areas to have a lowered skin temperature. These changes in blood flow distribution may cause the central body regions to have higher skin temperatures.

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APPENDIX

Individual Data

Table 5. Skin Temperature at the Arm in the Preflight Unsuited Condition

Subject	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	29.23	29.02	28.74	28.99	28.92	28.92	28.80	28.74	28.62	28.56
4599	30.72	30.60	30.66	30.53	30.41	30.35	30.35	30.38	30.32	30.38
3029	30.34	30.22	30.22	30.31	30.25	30.09	29.94	29.88	29.88	29.88
7264	31.76	31.82	31.82	31.64	31.67	31.48	31.42	31.33	31.33	31.21
4498	33.93	33.94	33.93	33.92	33.90	33.85	33.82	33.79	33.79	33.76
1233	31.36	31.30	31.12	30.87	30.52	30.61	30.61	30.61	30.56	30.53
1253	31.32	31.21	31.12	31.02	30.96	30.88	30.79	30.73	30.67	30.63
1135	30.88	30.73	30.73	30.63	30.35	30.22	30.13	30.10	30.10	30.16
7311	31.28	31.21	31.12	30.94	30.94	30.75	30.69	30.59	30.59	30.59
5660	34.85	34.85	34.88	34.85	34.85	34.88	34.53	34.24	34.08	33.87
3227	29.24	29.14	28.62	28.29	28.32	28.29	28.29	28.25	28.25	28.25
3522	28.58	28.38	28.46	28.38	28.50	28.54	28.54	28.54	28.42	28.42
3674	33.28	32.72	32.63	32.25	32.19	32.10	31.97	31.80	31.65	31.44
1930	30.67	30.95	30.70	30.64	30.51	29.91	29.65	29.52	29.46	29.29
3749	31.41	31.56	31.56	31.22	31.26	31.38	31.47	31.47	31.56	31.58
4498	31.99	32.02	31.99	31.95	31.90	31.75	31.66	31.60	31.60	31.52
1076	30.99	31.02	30.77	30.74	30.74	30.51	30.36	30.30	30.27	30.30
Mean	31.28	31.22	31.12	31.01	30.95	30.85	30.77	30.70	30.66	30.61
SE	0.39	0.40	0.41	0.41	0.41	0.41	0.40	0.39	0.39	0.39

Table 6. Skin Temperature at the Chest in the Preflight Unsuited Condition

Subject	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	30.43	30.19	30.03	30.03	29.88	29.82	29.69	29.60	29.39	29.39
4599	31.70	31.58	31.70	31.67	31.49	31.34	31.19	31.19	31.10	31.06
3029	30.43	30.65	30.65	30.87	30.87	31.03	30.97	31.09	31.09	31.09
7264	32.48	32.48	32.55	32.48	32.52	32.48	32.48	32.48	32.48	32.48
4498	33.92	33.95	33.91	33.96	33.96	33.94	33.88	33.84	33.84	33.84
1233	32.07	32.04	32.13	32.13	32.10	32.01	32.04	32.13	32.19	32.23
1253	31.65	31.62	31.53	31.68	31.59	31.50	31.50	31.50	31.38	31.29
1135	31.15	31.18	31.15	31.15	30.99	30.84	30.77	30.74	30.74	30.74
7311	31.30	31.33	31.33	31.21	31.27	31.02	30.96	30.87	30.84	30.65
5660	35.01	35.01	35.04	35.13	35.10	35.13	35.13	35.01	35.01	34.97
3227	30.17	29.94	29.81	29.81	29.81	29.81	29.84	29.84	29.94	29.94
3522	33.06	33.21	33.40	33.51	33.55	33.71	33.71	33.71	33.67	33.71
3674	33.78	33.56	33.47	33.29	33.32	33.17	33.17	33.01	32.92	32.86
1930	30.82	30.94	30.79	30.87	30.85	30.76	30.64	30.64	30.61	30.58
3749	32.59	32.65	32.65	32.65	32.56	32.56	32.53	32.65	32.68	32.78
4498	32.25	32.32	32.22	32.35	32.35	32.29	32.16	32.06	32.06	32.06
1076	32.41	32.48	32.38	32.41	32.32	32.28	32.28	32.28	32.28	32.35
Mean	32.07	32.07	32.04	32.07	32.03	31.98	31.94	31.92	31.90	31.88
SE	0.33	0.33	0.34	0.34	0.34	0.35	0.36	0.35	0.36	0.36

Table 7. Skin Temperature at the Thigh in the Preflight Unsuited Condition

Subject	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	29.86	29.65	29.52	29.52	29.19	28.70	28.54	28.42	28.54	28.48
4599	31.75	31.75	31.81	31.63	31.60	31.45	31.24	31.11	31.00	31.00
3029	29.92	29.92	29.89	29.76	29.82	29.70	29.22	28.94	28.82	28.75
7264	30.16	30.07	30.10	29.74	29.80	29.46	29.43	29.43	29.43	29.49
4498	33.78	33.81	33.81	33.84	33.87	33.84	33.69	33.69	33.69	33.69
1233	30.64	30.77	30.71	30.58	30.52	30.43	30.46	30.52	30.61	30.58
1253	30.30	30.33	30.36	30.39	30.42	30.46	30.49	30.49	30.46	30.42
1135	31.50	31.77	31.71	31.80	31.25	30.89	30.80	30.67	30.58	30.95
7311	31.00	31.13	31.22	30.94	30.66	30.41	30.23	30.13	30.07	30.32
5660	31.46	31.43	31.40	31.37	31.34	31.31	31.19	31.09	31.09	31.09
3227	29.72	29.53	29.49	29.66	29.53	29.39	29.30	29.30	29.33	29.33
3522	29.98	30.01	30.01	30.13	30.13	29.59	29.43	29.24	29.20	29.05
3674	31.17	31.02	30.96	30.99	31.05	30.18	30.03	29.97	29.87	29.84
1930	31.11	31.22	31.22	31.29	31.32	30.80	30.63	30.60	30.50	30.47
3749	32.68	32.78	32.81	32.81	32.81	32.59	32.46	32.43	32.56	32.62
4498	32.17	32.23	32.23	32.29	32.36	32.29	31.98	31.98	31.98	31.98
1076	32.22	32.28	32.31	32.31	32.19	31.88	31.56	31.41	31.32	31.29
Mean	31.14	31.16	31.15	31.12	31.05	30.79	30.63	30.55	30.53	30.55
SE	0.28	0.29	0.29	0.30	0.30	0.32	0.32	0.33	0.33	0.33

Table 8. Skin Temperature at the Calf in the Preflight Unsuited Condition

Subject	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	29.16	28.98	28.95	29.07	28.67	27.47	27.45	27.50	27.70	27.70
4599	31.36	31.27	31.08	31.05	30.99	30.87	30.62	30.77	30.96	31.20
3029	30.52	30.52	30.46	30.52	30.46	30.28	29.72	29.52	29.48	29.52
7264	30.53	30.56	30.59	30.31	30.16	29.92	29.73	29.73	29.76	29.86
4498	33.66	33.59	33.63	33.65	33.63	33.63	33.43	33.43	33.48	33.56
1233	31.89	31.83	31.38	31.26	30.92	30.85	31.17	31.47	31.71	31.90
1253	30.50	30.72	30.69	30.38	30.04	29.97	30.04	30.16	30.31	30.78
1135	31.23	31.47	31.66	31.60	31.17	31.26	31.56	31.78	31.88	32.35
7311	31.05	30.98	30.92	30.83	30.67	30.73	30.98	31.27	31.48	31.95
5660	32.20	32.20	32.17	32.07	32.17	32.08	31.83	31.86	31.99	32.07
3227	30.37	30.39	30.46	30.57	30.63	30.07	30.10	30.30	30.46	30.70
3522	30.70	30.86	31.01	31.19	31.19	31.19	31.42	31.81	32.33	32.76
3674	31.32	30.73	30.58	30.49	30.49	30.27	30.42	30.73	30.95	31.20
1930	31.83	31.83	31.89	31.98	31.98	31.65	31.50	31.47	31.50	31.59
3749	31.36	31.49	31.64	31.55	31.55	31.36	31.09	31.12	31.33	31.52
4498	32.21	32.08	32.15	32.18	32.15	32.15	31.79	31.79	31.87	32.02
1076	31.64	31.76	31.79	31.70	31.73	31.82	31.43	31.28	31.40	31.49
Mean	31.27	31.25	31.24	31.20	31.09	30.92	30.84	30.94	31.09	31.30
SE	0.24	0.24	0.24	0.25	0.27	0.32	0.31	0.31	0.31	0.33

Table 9. Mean Skin Temperature in the Preflight Unsuited Condition

Subject	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	29.70	29.49	29.33	29.43	29.21	28.86	28.75	28.69	28.65	28.62
4599	31.35	31.26	31.29	31.20	31.09	30.97	30.84	30.85	30.82	30.87
3029	30.32	30.35	30.33	30.41	30.39	30.33	30.06	29.98	29.95	29.94
7264	31.41	31.42	31.45	31.25	31.25	31.07	31.00	30.98	30.98	30.98
4498	33.85	33.85	33.84	33.86	33.86	33.83	33.73	33.71	33.72	33.73
1233	31.54	31.52	31.39	31.27	31.07	31.04	31.12	31.22	31.29	31.32
1253	31.05	31.06	31.00	30.96	30.86	30.80	30.79	30.80	30.77	30.82
1135	31.15	31.22	31.24	31.21	30.89	30.75	30.74	30.74	30.74	30.93
7311	31.18	31.19	31.16	31.00	30.93	30.76	30.74	30.72	30.74	30.83
5660	33.69	33.69	33.69	33.68	33.69	33.68	33.50	33.37	33.34	33.29
3227	29.84	29.71	29.52	29.47	29.47	29.32	29.32	29.35	29.42	29.46
3522	30.63	30.65	30.76	30.83	30.88	30.83	30.85	30.88	30.93	31.00
3674	32.61	32.23	32.14	31.96	31.96	31.67	31.63	31.58	31.53	31.50
1930	31.03	31.18	31.07	31.11	31.07	30.69	30.51	30.46	30.42	30.37
3749	32.01	32.12	32.15	32.03	32.02	31.97	31.91	31.95	32.05	32.14
4498	32.15	32.16	32.14	32.18	32.17	32.10	31.90	31.85	31.87	31.87
1076	31.79	31.86	31.76	31.75	31.70	31.58	31.39	31.31	31.31	31.35
Mean	31.49	31.47	31.43	31.39	31.32	31.19	31.11	31.08	31.09	31.12
SE	0.28	0.28	0.29	0.29	0.29	0.31	0.30	0.30	0.30	0.30

Table 10. Skin Temperature at the Arm in the Preflight Suited Condition

Subject	Suit	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	ACES	33.63	33.69	33.69	33.73	33.79	33.82	33.88	33.94	33.94	33.97
7973+	ACES	34.54	34.64	34.76	34.86	34.89	35.02	35.02	35.11	35.20	35.32
4599	LES	33.22	33.22	33.25	33.34	33.43	33.46	33.46	33.55	33.58	33.61
4599*	LES	30.49	30.46	30.43	30.40	30.40	30.40	30.40	30.37	30.34	30.30
8800*	ACES	32.74	32.58	32.49	32.37	32.34	32.58	32.74	32.93	33.21	33.69
3029	ACES	30.80	30.73	30.73	30.34	30.25	30.46	30.67	31.02	31.32	31.65
7264	LES	34.17	34.17	34.07	34.04	34.10	34.20	34.36	34.74	35.18	35.43
4498	ACES	34.88	34.92	34.94	34.94	34.95	35.03	35.03	35.05	35.12	35.23
1233	ACES	32.05	31.81	31.18	30.84	30.71	30.81	31.08	31.66	32.49	33.57
1253	ACES	30.14	30.11	29.95	30.02	30.17	30.42	30.73	31.11	31.38	31.65
1135	LES	32.04	31.92	31.70	31.70	31.76	31.98	32.17	32.45	32.58	32.58
7311	ACES	30.27	30.15	30.30	30.68	30.97	31.49	31.67	31.97	32.42	33.03
5660	ACES	34.63	34.59	34.46	34.53	34.63	34.82	34.85	34.72	34.56	
3227	ACES	28.78	28.59	28.52	28.62	28.78	29.04	29.30	29.62	29.82	30.09
3522	LES	31.60	31.04	30.78	30.55	30.89	31.20	31.30	31.49	31.64	31.79
3674	ACES	34.47	34.44	34.57	34.63	34.86	34.92	34.82	34.98	35.17	35.32
1930	ACES	33.34	33.25	33.07	33.04	33.25	33.58	34.00	34.03	34.12	34.47
3749	ACES	29.34	28.98	28.17	30.46	30.49	30.05	30.39	30.80	31.11	31.80
4498	ACES	34.66	34.76	34.82	34.82	34.85	35.07	35.07	35.13	35.32	35.62
1076	LES	26.70	26.64	26.95	27.20	27.44	27.92	28.32	28.74	29.11	29.38
Mean		32.04	31.94	31.83	31.97	32.08	32.25	32.42	32.65	32.87	33.07
SE		0.58	0.60	0.61	0.57	0.57	0.55	0.53	0.49	0.47	0.48

* Data from R+20 replaces preflight data for preflight vs. postflight comparison
\+ Data from R+30 replaces preflight data for preflight vs. postflight comparison

Table 11. Skin Temperature at the Chest in the Preflight Suited Condition

Subject	Suit	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	ACES	34.38	34.41	34.51	34.54	34.54	34.54	34.54	34.41	34.38	34.45
7973+	ACES	34.48	34.55	34.55	34.58	34.61	34.61	34.42	34.55	34.83	35.05
4599	LES	33.68	33.78	33.78	33.87	33.93	34.03	34.00	33.93	34.03	34.09
4599*	LES	28.09	27.66	27.41	27.41	27.90	28.53	29.03	29.53	29.90	30.40
8800*	ACES	32.83	32.61	32.20	31.92	31.86	32.30	32.27	32.20	32.14	32.32
3029	ACES	28.71	28.23	27.95	28.01	27.86	28.26	28.96	29.51	29.91	30.37
7264	LES	35.58	35.74	35.80	35.89	35.99	36.12	36.28	36.44	36.59	36.72
4498	ACES	34.12	34.17	34.19	34.23	34.24	34.28	34.34	34.34	34.36	34.47
1233	ACES	26.18	26.25	25.78	25.35	25.19	25.63	26.35	27.10	28.02	29.12
1253	ACES	30.64	30.57	30.76	30.97	31.16	31.44	31.68	32.01	32.39	32.77
1135	LES	28.72	28.28	28.28	28.56	28.91	29.46	29.84	30.18	30.43	30.56
7311	ACES	29.38	29.23	28.98	28.89	28.83	28.77	28.77	28.92	29.14	29.63
5660	ACES	32.40	32.58	32.55	32.61	32.80	33.08	33.01	32.95	32.74	
3227	ACES	27.97	27.61	27.74	28.17	28.54	28.90	29.09	29.25	29.28	29.41
3522	LES	34.33	34.02	33.67	33.14	33.14	33.25	33.36	33.63	33.94	34.17
3674	ACES	34.59	34.69	34.79	34.82	34.76	34.47	34.34	34.43	34.66	34.82
1930	ACES	33.65	33.65	33.68	33.83	33.92	34.01	34.10	34.22	34.53	34.94
3749	ACES	33.90	33.84	33.81	33.90	33.81	33.65	33.75	33.78	33.81	34.00
4498	ACES	32.71	32.84	32.88	32.97	33.00	33.10	33.23	33.23	33.29	33.54
1076	LES	26.30	26.27	26.58	27.02	27.41	28.02	28.40	28.80	29.18	29.51
Mean		31.60	31.54	31.51	31.58	31.65	31.82	32.00	32.18	32.39	32.66
SE		0.76	0.78	0.79	0.78	0.78	0.73	0.69	0.65	0.62	0.62

Table 12. Skin Temperature at the Thigh in the Preflight Suited Condition

Subject	Suit	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	ACES	32.84	32.90	32.96	32.96	32.96	33.09	33.17	33.15	33.17	33.20
7973+	ACES	33.94	34.03	34.06	34.06	34.15	34.18	34.21	34.30	34.43	34.50
4599	LES	33.33	33.33	33.24	33.33	33.42	33.45	33.58	33.58	33.70	33.83
8800*	ACES	29.38	29.04	28.74	28.09	27.93	28.71	29.35	29.75	30.17	30.47
3029	ACES	28.45	28.02	27.74	27.65	28.08	28.51	28.91	29.25	29.49	29.76
7264	LES	33.57	33.66	33.76	33.79	33.92	33.82	33.82	34.11	34.62	35.12
4498	ACES	34.85	34.85	34.85	34.86	34.91	34.97	34.97	35.03	35.10	35.19
1233	ACES	29.90	29.77	28.59	27.74	27.77	28.34	28.84	29.43	29.96	30.58
1253	ACES	26.18	26.06	26.25	26.78	27.31	27.89	28.45	28.94	29.59	30.33
1135	LES	29.68	29.46	29.34	29.65	29.80	30.05	30.34	30.64	30.92	31.22
7311	ACES	27.39	27.09	26.96	27.30	27.76	28.42	28.89	29.42	30.07	30.57
5660	ACES	29.00	28.85	28.67	28.54	28.64	28.76	29.10	29.31	29.49	
3227	ACES	28.44	28.18	28.04	28.38	28.74	29.06	29.26	29.46	29.63	29.85
3522	LES	32.41	32.53	32.61	32.84	33.00	33.08	33.08	33.08	33.08	33.08
3674	ACES	33.68	33.77	33.80	33.89	33.83	33.80	33.93	34.08	34.30	34.56
1930	ACES	33.89	33.89	33.89	33.82	33.76	33.79	33.95	34.23	34.58	34.98
3749	ACES	29.59	29.31	29.22	29.41	29.68	30.12	30.46	30.80	31.10	31.47
4498	ACES	34.44	34.44	34.44	34.48	34.57	34.70	34.70	34.83	34.98	35.17
1076	LES	32.78	32.85	32.97	33.10	33.25	33.43	33.55	33.68	33.84	33.96
Mean		31.20	31.12	31.02	31.09	31.26	31.49	31.70	31.94	32.21	32.68
SE		0.66	0.70	0.72	0.71	0.68	0.63	0.59	0.56	0.54	0.52

Table 13. Skin Temperature at the Calf in the Preflight Suited Condition

Subject	Suit	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	ACES	33.84	33.84	33.84	33.84	33.78	33.81	34.00	34.18	34.47	34.80
7973+	ACES	39.15	39.15	39.15	39.15	39.15	39.29	39.46	39.78	40.10	40.34
4599	LES	33.79	33.79	33.79	33.72	33.66	33.85	34.04	34.26	34.65	34.96
4599*	LES	28.73	29.30	29.89	30.71	31.59	32.76	33.55	34.21	34.80	35.09
8800*	ACES	31.60	31.30	31.05	30.89	30.89	31.20	31.72	32.40	33.15	33.76
3029	ACES	30.27	30.02	29.81	29.72	29.93	30.43	30.99	31.63	32.33	32.99
7264	LES	34.84	35.02	35.02	35.02	35.02	34.94	34.72	34.75	34.87	34.96
4498	ACES	35.22	35.19	35.19	35.19	35.20	35.27	35.39	35.59	35.74	35.88
1233	ACES	32.30	32.27	31.13	29.81	29.50	30.05	30.67	31.53	32.52	33.42
1253	ACES	26.71	26.58	26.83	27.20	27.72	28.49	29.36	30.41	31.70	32.82
1135	LES	33.11	32.92	32.76	32.70	32.92	33.57	34.19	34.87	35.41	35.95
7311	ACES	30.48	30.29	30.23	30.55	30.86	31.82	32.80	33.71	34.48	35.05
5660	ACES	28.76	28.67	28.64	28.70	29.06	29.58	30.07	30.59	31.16	
3227	ACES	28.66	28.30	28.06	28.06	28.36	28.89	29.47	30.17	30.89	31.55
3522	LES	34.15	34.15	34.15	34.04	33.92	33.96	33.96	34.24	34.43	34.79
3674	ACES	34.53	34.50	34.56	34.59	34.72	34.88	35.10	35.48	35.85	36.11
1930	ACES	34.53	34.49	34.49	34.49	34.49	34.56	34.74	34.99	35.32	35.70
3749	ACES	27.34	27.07	27.31	27.93	28.59	29.39	30.10	30.84	31.55	32.20
4498	ACES	34.99	34.93	34.93	34.93	34.96	35.08	35.30	35.64	35.92	36.17
1076	LES	31.49	31.49	31.58	31.67	31.73	31.85	31.95	32.19	32.54	32.86
Mean		32.06	31.97	31.90	31.89	32.03	32.38	32.76	33.24	33.76	34.39
SE		0.69	0.71	0.71	0.69	0.65	0.59	0.54	0.49	0.43	0.38

Table 14. Mean Skin Temperature in the Preflight Suited Condition

Subject	Suit	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	ACES	33.74	33.78	33.82	33.84	33.85	33.89	33.96	33.97	34.03	34.13
7973+	ACES	35.32	35.39	35.43	35.47	35.51	35.58	35.57	35.71	35.92	36.08
4599	LES	33.49	33.52	33.51	33.57	33.62	33.71	33.76	33.81	33.95	34.07
8800*	ACES	31.87	31.63	31.36	31.08	31.02	31.45	31.72	31.97	32.27	32.65
3029	ACES	29.60	29.30	29.12	28.98	29.04	29.41	29.87	30.33	30.73	31.16
7264	LES	33.57	33.66	33.76	33.79	33.92	33.82	33.82	34.11	34.62	35.12
4498	ACES	34.71	34.73	34.75	34.76	34.78	34.84	34.88	34.94	35.01	35.12
1233	ACES	29.91	29.83	29.03	28.37	28.22	28.61	29.13	29.82	30.65	31.61
1253	ACES	28.81	28.73	28.83	29.09	29.40	29.83	30.28	30.80	31.39	31.96
1135	LES	30.79	30.54	30.42	30.55	30.74	31.16	31.51	31.89	32.17	32.37
7311	ACES	29.47	29.29	29.22	29.44	29.66	30.13	30.47	30.89	31.38	31.92
5660	ACES	31.66	31.66	31.56	31.59	31.77	32.04	32.19	32.28	32.32	
3227	ACES	28.45	28.15	28.10	28.33	28.62	28.97	29.27	29.59	29.83	30.13
3522	LES	33.09	32.85	32.69	32.48	32.59	32.74	32.81	33.00	33.18	33.36
3674	ACES	34.36	34.39	34.48	34.53	34.59	34.55	34.55	34.74	34.98	35.18
1930	ACES	33.78	33.74	33.70	33.72	33.80	33.95	34.17	34.32	34.58	34.96
3749	ACES	30.36	30.12	29.90	30.77	30.94	31.01	31.35	31.70	32.01	32.47
4498	ACES	34.07	34.12	34.14	34.18	34.23	34.37	34.45	34.57	34.73	34.97
1076	LES	28.75	28.74	28.97	29.22	29.45	29.84	30.12	30.43	30.76	31.03
Mean		31.68	31.60	31.53	31.60	31.72	31.93	32.15	32.42	32.72	33.10
SE		0.55	0.57	0.58	0.58	0.57	0.53	0.49	0.45	0.43	0.43

Table 15. Skin Temperature at the Arm in the Postflight Suited Condition

Subject	Suit	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	ACES	33.05	33.08	33.26	33.53	33.41	33.41	33.53	33.57		
1299	LES	33.86	33.86	33.86	33.86	33.98	33.98	33.98	33.98	33.98	
4599	LES	32.67	32.67	32.64	32.61	32.70	32.80	32.89	32.92	32.92	
8800	ACES	30.25	29.75	29.28	29.03	28.85	29.07	29.19	29.47	29.66	29.91
3029	ACES	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90	21.90
7264	LES	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96	21.96
4498	ACES	36.21	36.24	36.27	36.30	36.33	36.33	36.33	36.33	36.33	36.33
1233	ACES	35.07	35.13	35.19	35.25	35.25	35.16	35.13	35.13	35.13	35.13
1135	LES	33.91	34.01	34.08	34.08	34.11	34.21	34.21	34.21	34.21	
7311	ACES	32.13	32.32	32.57	32.72	32.91	33.10	33.19	33.32	33.38	33.50
5660	ACES	33.56	33.56	33.59	33.59	33.65	33.73	33.79	33.83	33.95	34.11
1492	ACES	34.96	34.96	34.96	34.96	34.96	34.96	34.96	34.90	34.93	34.84
3674	ACES	34.18	34.18	34.18	34.25	34.31	34.31	34.31	34.53	34.85	35.10
4498	ACES	34.46	34.12	33.59	33.41	33.41	33.44	33.53	33.68	33.71	33.84
1076	LES	27.89	27.65	27.47	27.65	27.92	28.20	28.26	28.57	28.75	29.21
Mean		31.74	31.69	31.65	31.67	31.71	31.77	31.81	31.89	31.83	31.44
SE		1.15	1.16	1.17	1.17	1.17	1.17	1.17	1.16	1.24	1.56

Table 16. Skin Temperature at the Chest in the Postflight Suited Condition

Subject	Suit	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	ACES	33.38	33.38	33.41	33.44	33.50	33.53	33.62	33.62		
1299	LES	34.34	34.37	34.47	34.47	34.60	34.60	34.73	34.73	34.73	
4599	LES	34.45	34.45	34.45	34.45	34.54	34.66	34.83	34.83	34.95	
8800	ACES	31.86	31.74	31.58	31.40	30.88	31.16	31.40	31.68	31.80	31.71
3029	ACES	31.03	31.15	31.45	31.53	31.74	31.80	31.92	31.95	32.04	32.13
7264	LES	36.33	36.23	36.23	36.30	36.23	36.11	36.11	35.98	35.98	36.04
4498	ACES	35.97	36.07	36.07	35.87	35.78	35.56	35.43	35.31	35.08	35.05
1233	ACES	32.98	32.89	32.63	32.57	32.41	31.72	31.09	30.88	31.10	31.53
1135	LES	31.80	31.99	32.12	32.18	32.27	32.37	32.43	32.49	32.40	
7311	ACES	33.93	33.96	34.02	34.08	34.15	34.21	34.34	34.41	34.47	34.47
5660	ACES	35.43	35.49	35.55	35.55	35.55	35.52	35.36	35.27	35.18	34.99
1492	ACES	34.76	34.66	34.63	34.63	34.63	34.63	34.63	34.38	33.79	33.15
3674	ACES	34.08	34.21	34.27	34.18	34.18	34.37	34.43	34.43	34.40	34.43
4498	ACES	34.79	34.79	34.79	34.79	34.82	34.79	34.79	34.76	34.53	34.34
1076	LES	30.36	30.42	30.54	30.78	30.91	31.18	31.54	31.82	32.06	32.31
Mean		33.70	33.72	33.75	33.75	33.75	33.75	33.78	33.77	33.75	33.65
SE		0.46	0.45	0.45	0.44	0.44	0.43	0.43	0.41	0.41	0.47

Table 17. Skin Temperature at the Thigh in the Postflight Suited Condition

Subject	Suit	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	ACES	33.41	33.26	33.26	33.26	33.22	33.13	33.13	33.13		
1299	LES	32.86	32.89	32.98	32.98	32.98	32.98	33.01	32.98	32.98	
4599	LES	32.64	32.77	32.77	32.89	33.02	33.02	33.11	33.23	33.26	
8800	ACES	28.97	28.25	27.72	27.27	26.99	27.11	27.39	27.97	28.51	28.91
3029	ACES	28.88	29.10	29.22	29.34	29.49	29.66	29.75	29.88	30.13	30.65
7264	LES	32.30	32.24	32.24	32.30	32.33	32.36	32.36	32.36	32.36	32.46
4498	ACES	31.69	31.68	31.65	31.67	31.71	31.79	31.89	32.04	32.13	32.29
1233	ACES	32.10	32.16	32.23	32.32	32.35	32.35	32.35	32.51	32.76	32.97
1135	LES	30.46	30.56	30.64	30.70	30.79	30.79	30.79	30.86	31.04	
7311	ACES	29.87	30.12	30.31	30.47	30.62	30.91	31.13	31.40	31.61	31.86
5660	ACES	33.74	33.92	34.09	34.21	34.27	34.27	34.27	34.27	34.27	34.27
1492	ACES	32.93	32.87	32.78	32.68	32.63	32.60	32.65	32.68	32.68	32.68
3674	ACES	33.95	34.22	34.22	34.29	34.35	34.35	34.35	34.57	34.89	35.14
4498	ACES	32.93	32.30	31.54	31.37	31.43	31.72	32.11	32.29	32.51	32.84
1076	LES	28.63	28.88	29.10	29.25	29.43	29.76	30.10	30.44	30.75	31.14
Mean		31.69	31.68	31.65	31.67	31.71	31.79	31.89	32.04	32.13	32.29
SE		0.48	0.48	0.49	0.51	0.51	0.49	0.47	0.44	0.44	0.51

Table 18. Skin Temperature at the Calf in the Postflight Suited Condition

Subject	Suit	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	ACES	34.49	34.49	34.49	34.49	34.49	34.46	34.37	34.37		
1299	LES	32.88	32.88	33.00	33.00	33.00	33.03	33.12	33.12	33.12	
4599	LES	30.93	30.96	31.05	31.08	31.08	30.99	31.18	31.39	31.54	
8800	ACES	21.63	21.63	21.63	21.63	21.63	21.63	21.63	21.63	21.63	21.63
3029	ACES	30.52	30.70	30.83	30.95	31.05	31.17	31.32	31.62	31.92	32.36
7264	LES	32.23	32.22	32.24	32.26	32.28	32.33	32.44	32.64	32.72	32.77
4498	ACES	35.47	35.40	35.34	35.29	35.29	35.19	35.34	35.59	35.81	35.96
1233	ACES	33.27	33.27	33.27	33.27	33.17	33.14	33.14	33.30	33.62	33.97
1135	LES	33.70	33.82	33.82	33.82	33.85	33.95	34.04	34.52	35.03	
7311	ACES	33.43	33.43	33.53	33.56	33.56	33.56	33.62	33.68	33.68	33.71
5660	ACES	31.74	31.86	32.04	32.17	32.35	32.60	32.70	32.82	32.82	32.79
1492	ACES	34.32	34.32	34.19	34.19	34.19	34.19	34.16	34.16	34.22	34.36
3674	ACES	32.87	32.87	32.97	33.00	33.03	33.27	33.67	34.24	34.81	35.24
4498	ACES	33.69	33.20	32.95	32.89	32.89	33.11	33.44	33.94	34.43	34.90
1076	LES	32.23	32.22	32.24	32.26	32.28	32.33	32.44	32.64	32.72	32.77
Mean		32.23	32.22	32.24	32.26	32.28	32.33	32.44	32.64	32.72	32.77
SE		0.83	0.82	0.82	0.82	0.82	0.82	0.82	0.84	0.91	1.17

Table 19. Mean Skin Temperature in the Postflight Suited Condition

Subject	Suit	-5.00	-4.00	-3.00	-2.00	-1.00	1.00	2.00	3.00	4.00	5.00
7973	ACES	33.51	33.49	33.55	33.64	33.62	33.60	33.64	33.65		
1299	LES	33.61	33.62	33.70	33.70	33.77	33.78	33.84	33.83	33.83	
4599	LES	32.85	32.88	32.89	32.91	32.99	33.04	33.17	33.25	33.32	
8800	ACES	28.75	28.42	28.13	27.91	27.64	27.82	27.98	28.27	28.46	28.59
3029	ACES	27.76	27.88	28.01	28.09	28.20	28.28	28.36	28.45	28.59	28.81
7264	LES	30.39	30.35	30.35	30.39	30.38	30.36	30.38	30.38	30.40	30.45
4498	ACES	35.54	35.56	35.55	35.49	35.48	35.41	35.43	35.47	35.51	35.71
1233	ACES	33.49	33.49	33.45	33.46	33.40	33.16	32.97	32.97	33.14	33.39
1135	LES	32.55	32.68	32.75	32.78	32.84	32.92	32.96	33.08	33.20	
7311	ACES	32.48	32.59	32.74	32.85	32.96	33.09	33.21	33.33	33.42	33.51
5660	ACES	33.79	33.87	33.97	34.02	34.08	34.15	34.14	34.15	34.16	34.14
1492	ACES	34.36	34.32	34.27	34.25	34.24	34.23	34.24	34.15	33.99	33.80
3674	ACES	33.84	33.94	33.97	33.98	34.02	34.13	34.23	34.45	34.71	34.94
4498	ACES	34.10	33.77	33.41	33.31	33.33	33.43	33.61	33.78	33.86	34.00
1076	LES	32.23	32.22	32.24	32.26	32.28	32.33	32.44	32.64	32.72	32.77
Mean		32.62	32.61	32.60	32.60	32.62	32.65	32.71	32.79	32.81	32.74
SE		0.55	0.55	0.56	0.56	0.57	0.56	0.55	0.54	0.57	0.72

Table 20. Skin Temperature at the Arm (left) and Chest (middle) and Calf (right) during Landing Events

ID	D/O Burn	Wheel Stop	Hatch Open	Exit Orbitor	D/O Burn	Wheel Stop	Hatch Open	Exit Orbitor	D/O Burn	Wheel Stop	Hatch Open	Exit Orbitc
7973	35.41	35.52	34.45	34.21	35.46	36.15	35.89	35.03	34.89	34.89	34.64	34.18
1299	34.59	34.51	33.89	33.20	35.72	34.77	33.69	32.87	34.35	32.49	32.12	31.64
4599	35.41	34.67	34.40	33.81	36.19	36.02	35.27	34.45	33.89	34.06	33.51	32.65
8800	35.67	33.40	33.49	34.16	36.00	34.53	34.53	35.16	33.18	30.40	30.40	30.95
7264	34.04	33.67	33.72	33.66	32.33	35.57	36.23	36.25	29.96	32.24	32.58	32.51
4498	35.21	35.76	36.09	35.80	36.09	36.59	35.90	35.77	33.04	32.04	31.87	31.79
1233	29.52	31.35	33.82	33.41	28.79	31.97	34.05	32.75	28.37	29.27	30.65	31.37
1253	30.19	31.59	31.53	31.49	26.73	27.41	26.92	26.65	31.47	31.88	32.38	32.22
1135	35.34	33.32	33.35	33.12	35.48	31.31	30.84	30.71	33.36	29.44	29.33	29.27
7311	34.94	33.28	32.59	33.19	35.24	34.29	33.64	33.05	34.57	30.18	30.12	29.32
5660	36.18	34.09	34.31	34.09	36.68	35.38	35.01	34.94	35.59	33.23	32.85	32.74
1492	33.87	34.39	34.21	34.82	35.13	35.49	34.03	35.23	33.42	33.54	31.26	32.02
4498	33.40	33.67	34.08	34.02	33.08	33.74	34.21	33.69	33.31	32.64	32.88	32.66
1076	32.75	32.19	32.15	32.31	34.01	33.42	33.09	33.13	33.20	32.31	31.57	31.78
Mean	34.04	33.67	33.72	33.66	34.07	34.05	33.81	33.55	33.04	32.04	31.87	31.79
SE	0.54	0.35	0.30	0.28	0.79	0.66	0.64	0.66	0.52	0.45	0.38	0.35

Table 21. Skin Temperature at the Calf (left) and Mean (right) during Landing Events

ID	D/O Burn	Wheel Stop	Hatch Open	Exit Orbitor	D/O Burn	Wheel Stop	Hatch Open	Exit Orbitor
7973	34.60	35.10	35.34	34.81	35.16	35.50	35.09	34.57
1299	34.60	32.88	32.33	31.69	34.88	33.85	33.16	32.49
4599	31.44	31.79	31.76	30.80	34.55	34.38	33.95	33.17
8800	32.85	32.65	32.62	32.33	34.71	32.99	33.01	33.45
7264	32.85	32.65	32.62	32.33	32.47	33.75	34.02	33.94
4498	34.28	34.67	34.88	35.41	34.86	35.05	34.95	34.91
1233	28.57	31.30	33.03	31.32	28.88	31.11	33.10	32.39
1253	27.18	26.79	26.67	26.46	28.81	29.43	29.35	29.18
1135	33.70	32.27	32.19	32.11	34.66	31.73	31.56	31.43
7311	34.69	33.56	33.19	32.85	34.91	33.02	32.53	32.31
5660	35.82	32.82	32.20	32.16	36.14	34.05	33.81	33.69
1492	33.44	34.70	33.47	34.07	34.07	34.61	33.42	34.23
4498	33.02	33.27	33.72	33.91	33.21	33.40	33.81	33.63
1076	32.85	32.65	32.62	32.33	33.24	32.67	32.41	32.45
Mean	32.85	32.65	32.62	32.33	33.61	33.25	33.16	32.99
SE	0.64	0.54	0.53	0.57	0.59	0.44	0.39	0.39

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The two flight suits currently worn by crew members during Shuttle launch and landing, the Launch and Entry Suit (LES) and the Advanced Crew Escape Suit (ACES), are designed to protect crew members in the case of emergency. Although the Liquid Cooling Garment (LCG) worn under the flight suits was designed to counteract the heat storage of the suits, the suits may increase thermal stress and limit the astronaut's egress capabilities. The purpose of this study was to assess the thermal loads experienced by crew members during a simulated emergency egress before and after spaceflight. Comparisons of skin temperatures were made between the preflight unsuited and suited conditions, between the pre- and postflight suited conditions, and between the two flight suits.

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