Heat Stress and Carbon Monoxide Exposure During C-130 Vehicle Transportation

ALEX DOR, RUSSELL POKROY, LIAV GOLDSPEIN, EREZ BARENBOIM, AND MICHAL ZILBERBERG

THE C-130 AIRCRAFT is often used for military vehicle airlift. Loading vehicles with hot engines into the C-130 cabin, as well as hot climatic conditions and direct convection heating of the aircraft on the runway, may cause heat stress to the aircrew (6,11). Heat stress may cause dehydration, mental slowing, and poor task performance (5,7,8,11). In addition, driving the vehicles on and off the aircraft is a potential source of cabin contamination by exhaust gases. The most toxic contaminant, carbon monoxide (CO), may cause fatigue, headache, nausea, and even death (3,4). Even low levels of CO may exacerbate the hypoxic stress of high altitude flights. Although we do not know of an environmental interaction between heat stress and CO, running gasoline engines in the confines of the C-130 cabin is a source of both these environmental hazards. In order to ensure the safety of C-130 aircrew, we undertook this study, which was aimed at investigating heat stress and CO exposure during C-130 vehicle transportation.

METHODS

Data were collected from two night (18:00–08:00) and two day (08:00–18:00) C-130 flights performed in Israel during the summer of 2003. Both day and night flights were studied to assess the effects of various ambient temperatures and direct convection heating from the sun and runways. The aircraft, waiting on a concrete runway before takeoff, and the vehicles, waiting in desert terrain with engines running for the aircraft arrival, were exposed to extreme atmospheric conditions. Each flight had a pre-vehicle loading leg, during which control data was collected, immediately followed by vehicle loading. The transported vehicles were jeep-like vehicles powered by four-cylinder 2000 cm$^3$ gasoline engines. Either two or three vehicles were transported per flight. Of the two day flights, one transported two vehicles and the other transported three. Likewise, the two night flights transported two and three vehicles, respectively. The vehicles were loaded by the power of their own engines by ascending the aircrafts’ ramp, advancing and reversing until they were correctly positioned. The three-man aircrew, while standing in the C-130 cabin, directed the vehicles to their respective flying positions. Vehicle loading required 15–30 min. The aircraft air conditioning system was operated continually for day flights and during takeoff alone for night flights.

Dry bulb temperature and cabin heat stress index (wet bulb globe temperature, WBGT) were measured and calculated at 10-min intervals by a QuestTemp-15 Heat Stress Monitor (Quest Inc., Oconomowoc, WI). Runway ambient temperature was measured immediately before takeoff and after landing by a handheld monitor 1.5 m above the runway. Carbon monoxide was measured at 30-s intervals by using an inorganic gas monitor (RAE Systems, Sunnyvale, CA). As shown

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in Fig. 1, both monitors were fixed centrally in the cabin 1.5 m above the floor. We fixed the monitors at this height, the breathing zone of a crewmember standing upright, since vehicle loading was performed in this position. The heat stress and gas monitors were equipped with onboard lodgers, enabling temperature and CO measurement recordings for the entire flight duration. After each flight, the measurements were downloaded onto a personal computer for statistical analysis.

Our measurements were compared with the recommended exposure limits of the American Conference of Governmental Industrial Hygienists (1,2). We used the recommended cabin temperature exposure limit of 28°C (1) since this is the recommended limit for heavy work performed by non-acclimatized crewmembers for approximately 25% of the workshift. The threshold-limited value time-weighted average of 25 ppm (2) was used for the assessment of CO exposure.

We used a computer spreadsheet program (Statistical Product and Service Solutions, Version 11.0, SPSS Inc., Chicago, IL) to analyze our results. The Student’s t-test was used for normally distributed data and Fisher’s exact test and Mann-Whitney U test for nonparametric data. Regression analysis was used for heat stress prediction.

RESULTS

The transport durations, defined as the period that the vehicles were in the C-130 cabin, ranged from 80–160 min. The flight durations, defined as the period from the first takeoff through the control flight leg, loading the vehicles, and the transport duration until the final landing, ranged from 170–260 min. The cabin mean WBGT during vehicle transportation was significantly higher than in control flights (Table I). Fig. 2 demonstrates the sharp increase in WBGT after vehicle loading in flight 1. The three vehicles’ hot engines and bodies added 5.9°C to the cabin WBGT (compared with the control flight). Although the cabin cooling system was activated, the WBGT continued to rise until vehicle unloading, maintaining a heat stress above the heat stress-recommended limit (28°C) for the entire duration of the transportation. The WBGT peaked at 37.5°C 140 min after vehicle loading.

<table>
<thead>
<tr>
<th>Flight No./Day or Night</th>
<th>Ambient Temp* (°C)</th>
<th>Transport Duration (min)</th>
<th>No. of Vehicles</th>
<th>WBGT† During Vehicle Transportation (°C)</th>
<th>WBGT without Vehicle (Control Flight) (°C)</th>
<th>p-value‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/day</td>
<td>32.4</td>
<td>160</td>
<td>3</td>
<td>35.8 ± 1.1</td>
<td>29.9 ± 1.4</td>
<td>0.0001</td>
</tr>
<tr>
<td>2/day</td>
<td>29.4</td>
<td>80</td>
<td>2</td>
<td>27.8 ± 1.9</td>
<td>25.5 ± 1.0</td>
<td>0.0001</td>
</tr>
<tr>
<td>3/night</td>
<td>19.1</td>
<td>90</td>
<td>2</td>
<td>20.2 ± 1.5</td>
<td>16.7 ± 1.0</td>
<td>0.0001</td>
</tr>
<tr>
<td>4/night</td>
<td>18.4</td>
<td>130,50</td>
<td>3</td>
<td>20.5 ± 1.9</td>
<td>17.0 ± 2.3</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

Data presented as mean ± SD.

*Mean temperature on the runway, measured before takeoff and after landing (flight 3, before takeoff alone).

†WBGT = wet bulb globe temperature, heat stress index.

‡The significance of the mean heat stress index difference, calculated by non-parametric t-test.
DISCUSSION

Vehicle loading for C-130 airlifts caused sharp WBGT increases in the C-130 cabin. The heat stress continued to increase in flight for varying durations, ranging from 60 to 140 min in flights 2 and 1, respectively. This shows that hot vehicles emit heat for up to 140 min. In the absence of effective cooling, the cabin WBGT continues to rise. In flight 1, the C-130 cabin cooling system was overwhelmed, effecting insignificant cooling, and the heat emitted by the vehicles remained trapped in the cabin. The WBGT rose above 32.5°C, the highest limit accepted by the American Conference of Governmental Industrial Hygienists (1). In flight 2, with the cooling system active, the cabin WBGT did taper, but only 60 min after vehicle loading. In flights 3 and 4, the cooling system was not used due to cool ambient temperatures, and the heat stress increased for 70 and 80 min, respectively; this accumulation of emitted heat in the C-130 cabin explains why the flight duration is related to the heat stress. During flight 4, the same vehicles were unloaded and immediately reloaded as a military exercise, not allowing the vehicle engines to fully warm up. This second loading of flight 4 caused little increased heat stress since the vehicle engines were cool.

Another cause of heat stress on the cabin crew is radiant solar energy. Solar heating of the C-130 body while awaiting takeoff on the runway caused the high WBGTs recorded in the day flights before vehicle loading. In our study, comparing the WBGT of day and night control flights (before vehicle loading) showed that daytime ground standby may significantly increase cabin WBGT. Similarly, Froom et al. (6) showed an additional 7°C increase of cabin temperature after helicopters waited 1 h on the ground under the sun.

The CO levels increased to just above the TLV in the three-vehicle night flight and approached the action level (half of the TLV, signifying a warning level at which industrial hygienists would recommend preventive actions) in the three-vehicle day flight. This finding corresponds with other studies that show a correlation between increased CO levels and the number of engines working simultaneously in a closed, poorly ventilated space (10). However, since this TLV is based on an 8-h work shift and our longest transport duration was only 160 min, the CO exposure is well below the TLV-time weighted average formula and not considered hazardous.

The C-130 plane was first used in 1956 for military aircraft support. The air conditioning system of the early C-130 models is dated and, like other corresponding systems in an older aircraft (9), provides inadequate cooling under conditions of severe heat stress. We recommend increasing the natural ventilation of the plane.

**TABLE II. CABIN MEAN (RANGE) CARBON MONOXIDE LEVELS (PPM).**

<table>
<thead>
<tr>
<th>Day or Night</th>
<th>Three Vehicles</th>
<th>Two Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight</td>
<td>Transported</td>
<td>Transported</td>
</tr>
<tr>
<td>Day</td>
<td>12.4 (1.266)</td>
<td>4.2 (0.8–27.3)</td>
</tr>
<tr>
<td>Night</td>
<td>25.5 (1.401)†</td>
<td>7.7 (0.2–52)</td>
</tr>
</tbody>
</table>

*The significance of the mean cabin carbon monoxide, calculated by non-parametric t-test.
†The mean cabin carbon monoxide slightly exceeded the threshold-limited value of 25 ppm.
before takeoff by opening the front and the rear door
during ground stand-by, and using industrial fans on
the runway during loading if the ambient temperature
exceeds 28°C. Naturally, improved C-130 cabin cooling
systems would help prevent in-flight heat buildup dur-
during vehicle transport.

Our study showed that hot transported vehicles sig-
ificantly add to heat stress development, especially if
the ambient temperature is above 31°C before takeoff.
The in-flight WBGT can be predicted by considering the
ambient temperature, the number of transported vehi-
cles, and the flight duration after vehicle loading. Three
or more transported vehicles may significantly increase
the cabin CO level without adversely affecting crew-
members.

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