

Analysis of Convective Heat Transfer in the Orbiter Middeck for the Shuttle Rescue Mission

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ABSTRACT

The paper presents the results of a CFD study for predictions of ventilation characteristics and convective heat transfer within the Shuttle Orbiter middeck cabin in the presence of seven suited crewmember simulation and Individual Cooling Units (ICU). For two ICU arrangements considered, the thermal environmental conditions directly affecting the ICU performance have been defined for landing operation. These data would allow for validation of the ICU arrangement optimization.

INTRODUCTION

As part of the Shuttle Orbiter Return to Flight (RTF) effort, a Launch on Need (LON) mission has been designed that would to rescue the crew of a Space Shuttle if their vehicle was damaged and deemed unable to make a successful reentry. LON mission design specifies that the rescue vehicle will be manned by a four member crew that will rescue a stranded seven member crew. During entry, four suited crewmembers will be in the flight deck, and seven will be in the middeck. To provide heat removal capability from the crew body, each crew suit is supplied with a water loop of a small-diameter tube that is connected to the Individual Cooling Unit (ICU). Each ICU, looking as a small box, is a heat pump where warm water from the water loop is cooled by the flowing cabin air. Seven ICU will be placed in the middeck during the LON reentry to ensure cooling of seven crewmembers.

Having analyzed estimations obtained for the thermal state of the Orbiter on the basis of the lumped parameter model, it was suggested that information on the volume-averaged middeck air temperature could be not enough to estimate the ICU performance. It was suggested that ICU arrangement should take into account specifics of local airflow structure and spatial temperature distribution within the middeck volume. Consequently, a detailed three-dimensional (3D) Computational Fluid Dynamics (CFD) analysis for ventilation characteristics and heat transfer in the presence of seven ICU was necessary to ensure a good performance of all the ICU and not to expose the crewmembers to a possible high cabin temperature.

The main goal of the study is to check if the temperature of the cooling air supplied to the middeck ICU inlets under the LON reentry conditions is in the required operating range. Two computational runs, Case 1 and Case 2, are considered. Both the cases are analyzed under zero-gravity conditions as they correspond to an instant before the Orbiter touchdown. The study has been performed with the FLUENT 6.3.26 CFD software [1].

COMPUTATIONAL MODEL

MIDDECK GEOMETRY AND VENTILATION AIRFLOW - Figure 1 shows two Orbiter middeck geometry models adopted for computations in Case 1 and Case 2. For both cases, the models of the cabin middeck volume is approximately equal to 750 ft³. The models include the middeck interior with some geometry simplifications.

Seven ECLOID (Environmental Control and Life Support System – ECLSS – AndrOID) were incorporated into both the geometry models. Four ECLOIDs were placed in the forward side of the middeck, and three ECLOIDs were placed in the aft side of the middeck called the ditch area.

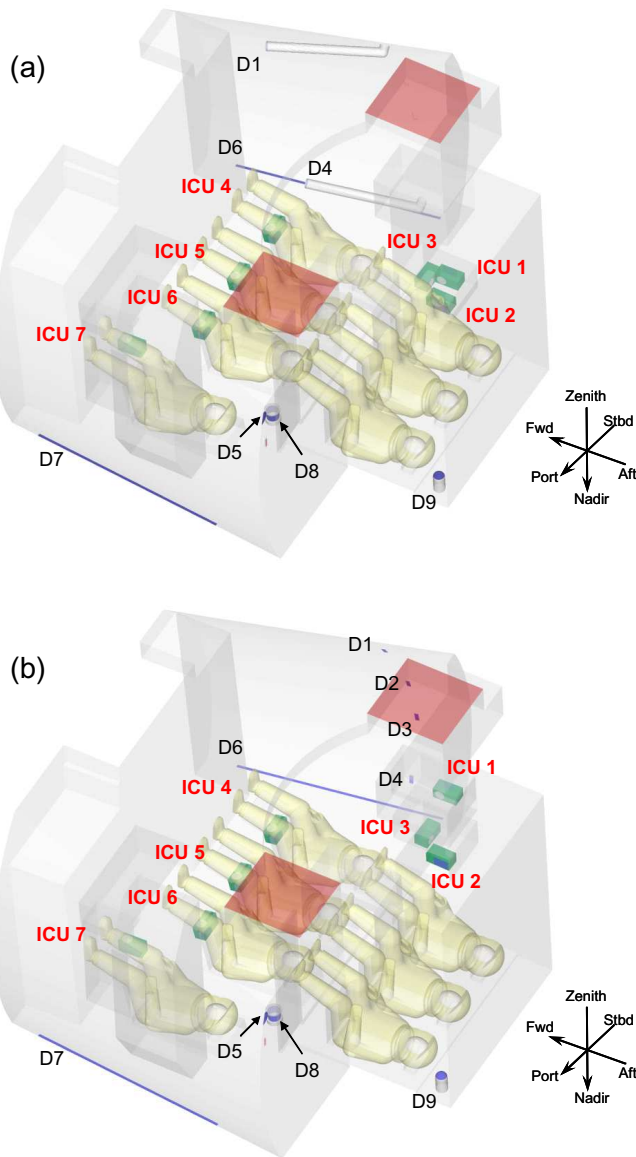


Figure 1. Orbiter middeck geometry adopted for computations: (a) Case 1 and (b) Case 2.

Seven ICU are incorporated into the middeck geometry model as well. The ICU boxes are modeled as parallelepipeds, each with a circular influent (treated, in fact, as an outlet for the middeck cabin air) and a rectangular effluent (an inlet for the middeck cabin air). The ICU models are marked by green in Figure 1. Forward ICU 4, 5, 6, and 7 are assigned for the crewmembers placed in the forward part of the middeck and are attached to the seats separately. Aft ICU 1, 2, and 3 serve for the crewmembers placed in the so called, ditch area, which is near the airlock hatch. In the initial arrangement adopted for Case 1 all three ditch-

area ICU are mounted within the same small open storage just above the floor (see Figure 1a). An alternative configuration is assumed in Case 2 where two other storages are emptied and used for the ditch-area ICU arrangement – the first one for ICU 1, and the second one for ICU 2 and 3. These storages are located one above another several feet higher as compared with the initial configuration. The ditch-area ICU orientation is the same in both the cases.

The middeck ventilation system is modeled by means of nine inlets (marked as D1-D9 in Figure 1), namely four starboard diffusers, port semicircular diffuser, forward floor diffuser, aft floor diffuser, and two gaps in the deck corners. All these inlets are supposed to be supplied with revitalized air from Heat Exchanger (HX).

In Case 1 the total flow rate through the HX of 147 cfm is adopted that corresponds to 11.8 Air Changes per Hour (ACH). In Case 2 with the total HX flow rate of 188 cfm that corresponds to 15 ACH.

Only one of two floor diffusers can be utilized during the LON flight. In both the cases considered, the aft floor diffuser (D9) is open while the forward floor diffuser (D8) is closed. Preference of the ventilation system configuration with the open aft floor diffuser was justified previously by 3D airflow and CO₂ gradients analysis [2]. An effective hemisphere with a prescribed uniform radial velocity was used as the aft floor diffuser inlet section.

In Case 1 two middle starboard diffusers, D2 and D3, are closed, and two flexible ducts are connected to two end starboard diffusers (placed at the zenith and nadir sides). In Case 2 all four starboard diffusers are open; the flexible ducts are not used.

Each of two thin deck gaps of one inch by six feet (D6 and D7) provides 25 lbm/hr of air. The gaps are placed in the corners between the side walls and the deck. These gaps are introduced into the computational model to represent the airflow seeping through to the middeck from the Environment Control and Life Support (ECLS) bay located beneath the floor.

Air leaves the middeck interior through a small outlet to the toilet and two hatches that connect the middeck with the flight deck (the hatches are marked by red in Figure 1). The pressure outlet boundary condition is set at the outlet-to-toilet section (flow rate of -11 cfm). It is assumed that the flow rate leaving the middeck interior through the hatches is divided equally.

It is prescribed that each ICU provides pumping of 45 cfm of air. This value was set as the operating ICU flow rate on the basis of test data. According to this, the given velocity boundary conditions are set at seven circular outlet sections (ICU influents), the total flow rate is -315 cfm. This air is delivered back to the middeck cabin through correspondent seven inlet sections (rectangular ICU effluents) with the same flow rate.