

CFD Study of Ventilation and Carbon Dioxide Transport for ISS Node 2 and Attached Modules

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ABSTRACT

The objective of this study is to evaluate ventilation efficiency regarding to the International Space Station (ISS) cabin ventilation during the ISS assembly mission 1J. The focus is on carbon dioxide spatial/temporal variations within the Node 2 and attached modules. An integrated model for CO₂ transport analysis that combines 3D CFD modeling with the lumped parameter approach has been implemented. CO₂ scrubbing from the air by means of two ISS removal systems is taken into account. It has been established that the ventilation scheme with an ISS Node 2 bypass duct reduces short-circuiting effects and provides less CO₂ gradients when the Space Shuttle Orbiter is docked to the ISS. This configuration results in reduced CO₂ level within the ISS cabin.

INTRODUCTION

The air quality is largely dependent on the concentration of carbon dioxide in the atmosphere. Engineering models for CO₂ concentration prediction utilize the assumption that each module of the International Space Station is well ventilated and mixed, i.e. that the CO₂ concentration is uniform throughout the module. This assumption is adequate for most cases when CO₂ sources are not in a fixed location and when air ventilation is in normal operation. Computational Fluid Dynamics (CFD) models produce more detailed information concerning the air quality, such as CO₂ gradients within the ISS modules and mixing characteristics. Gradient analysis is especially important

for off-nominal and other contingency operation on orbit that might occur in the ISS flights.

The ISS ventilation capability is accomplished by exchanging air between modules (inter-module ventilation, IMV) as well as circulating air within a module (intra-module ventilation). The contribution of the intra-module ventilation to CO₂ transport could be successfully computed using single ISS module model. An example of such single-module computations for the ISS Node 2 is given in [1]. However, an adequate evaluation of the inter-module ventilation contribution into CO₂ transfer, as well as the crewmember location in different parts of the ISS, requires the use of an integrated ISS CFD model [2].

During the Space Shuttle Orbiter missions to the Space Station, the ISS Environmental Control and Life Support Systems (ECLSS) provide atmosphere revitalization not only for the Station, but for the Orbiter as well. The subject of airflow and air quality has increased in importance, following notes from several previous Space Shuttle missions on high CO₂ when the Orbiter is docked to the ISS.

The current contribution is devoted to application of an integrated model for CO₂ transport analysis to the ISS assembly mission 1J configuration. The mission 1J was performed in May 2008 to deliver the Pressurized Module and robotic arm of the Japanese Experiment Module "Kibo" [4]. The goals of the study are (i) to evaluate the ventilation characteristics of the JPM module delivered and added to the station and (ii) to

check a possibility to improve the Orbiter ventilation when docked to the ISS. Two cases were analyzed, varying in Orbiter/ISS air exchange scenarios. The study has been developed with the FLUENT 6.3.26 CFD software [5].

COMPUTATIONAL MODEL

PROBLEM FORMULATION - The integrated model for CO₂ transport analysis combines 3D CFD modeling with the lumped parameter approach. 3D flow and mass transfer simulation is performed considering six ISS modules located in the forward part of the Station, namely, the U.S. Laboratory (USL), Node 2, Columbus, the Japanese Pressurized Module (JPM), the Japanese Logistics Module (JLP), and the Pressure Mating Adapter 2 (PMA 2). An outside view from the forward part of the Station is given in Figure 1. The 3D computational domain used for the ISS ventilation CFD analysis is illustrated in Figure 2. The habitable cabin aisle volume of the forward part of the ISS taken into account by the CFD model is 5830 ft³.

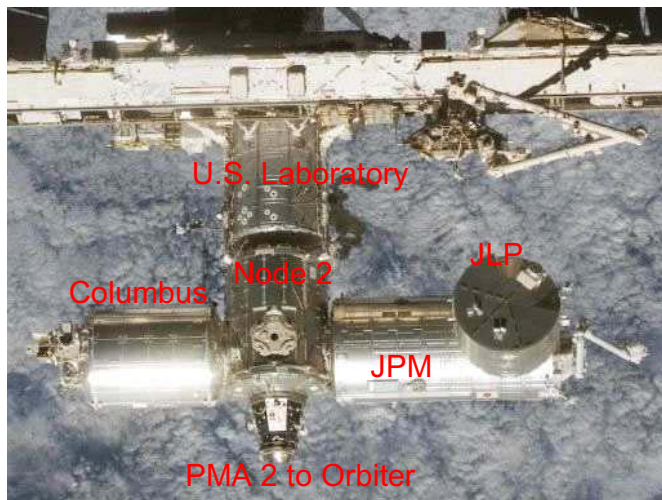


Figure 1. A view of Node 2 and attached modules during the ISS assembly mission 1J.

Remaining ISS modules that are located in the aft part of the Station, namely, Node 1, that is directly attached to the aft hatch of USL, the U.S. Airlock, Docking Compartment 1, Pressurized Mating Adapter 1 (PMA 1), the Functional Cargo Block, and the Service Module (SM) [6], are modeled via the lumped-parameter approach that takes into account the total volume of the aft part of the Station of 9005 ft³. The Orbiter that is attached to the forward hatch of Node 2 via PMA 2 is modeled using the lumped-parameter approach as well (the Orbiter volume of 1412 ft³ is considered).

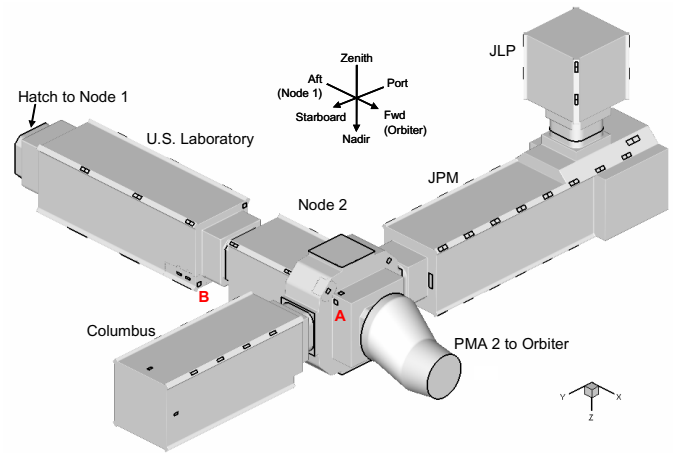


Figure 2. Computational domain for 3D CFD CO₂ transport simulation.

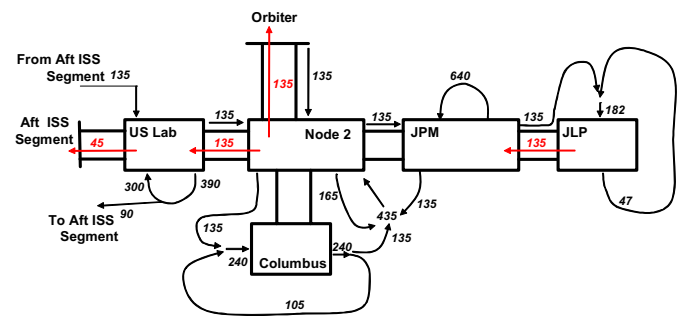


Figure 3. Flow rates (in cfm) adopted for computations: the basic ventilation configuration.

The basic ISS ventilation scheme is illustrated in Figure 3. The total intra-module and IMV flow rates (in cubic feet per minute) are given in the figure. The airflows through boundaries of the computational domain (diffusers and return grills, treated with proper boundary conditions) are marked by black, while the hatch inter-module flows are marked by red. Each ISS module has its own intra-module ventilation system. First, IMV sub-systems with flexible ducts are located in Node 2 and supply the attached modules, Columbus and JPM, with Node 2 air. IMV air returns back to Node 2 also by means of ducts. Second, air from JPM is supplied to JLP through an IMV duct and returns back via an open hatch. Finally, air from the aft ISS segment (namely, from the Service Module in the Russian segment) is introduced into the USL module aft-port IMV diffuser through a duct. IMV air from the USL partially moves back to the SM through an open hatch, and partially through the return IMV duct.

During the Space Shuttle is docked, the Orbiter is supplied with 135 cfm of relatively clean air from the Station via an open hatch, while one of the spare ISS IMV duct systems provides return air flow to the Station. For the basic ventilation configuration illustrated in Figure 3, a Node 2 IMV sub-system is used for the Orbiter/ISS air exchange. The IMV duct is attached to the Node 2 forward-starboard IMV diffuser marked as "A" in Figure