

Flammability of Human Hair in Exploration Atmospheres

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ABSTRACT

To investigate the flammability of human hair, a series of normal and microgravity flame spread tests over human hair were performed in a low-speed flow tunnel to simulate spacecraft ventilation flows (~20 cm/s). The tunnel atmosphere pressure and oxygen concentration was varied over the range of anticipated exploration atmospheres (21-34% O₂ in N₂, 8-14.7 psia). While hair is marginally flammable in air, spreading upward but not downward, it burns extremely well at or above 30% O₂ in any direction or g-level. The spread is characterized by a quick spread over the surface 'nap' or 'frizz', followed by continued bulk burning. Two hair 'styles' were tested – short hair and long hair – and style does not seem to affect initial nap spread significantly.

Opposed and concurrent nap spread rates are similar in 0g under comparable conditions. Oxygen concentration has a strong effect on flame spread rates. Concurrent spread rates are more than an order of magnitude faster in 30% O₂ compared to 21% O₂. Gravity also affects flame spread, with 1g concurrent (upward) being the fastest spread. For concurrent spread, 1g spread is faster than 0g spread, so it is reasonable to assume Lunar and Martian environments would also support faster concurrent flame spread. Surprisingly, however, for opposed flow, 0g spread is faster than 1g (downward) spread, so the generalization to Martian and Lunar environments cannot be made for opposed flow. Pressure has little effect on tip spread rate. Subsequent bulk burning appears weaker at lower pressure.

INTRODUCTION

The flammability of human skin and hair has been a concern since the early days of the human space program and the introduction of elevated oxygen concentrations for the crew cabin atmosphere [1]. To quantify the potential fire hazard during future exploration missions, NASA is studying flow conditions, materials, and ignition sources that would exist in credible elevated oxygen scenarios. For example, the fire hazard greatly increases when one considers that the crew will have flammable clothing and hair as they respond to a fire event in the elevated oxygen cabin atmosphere. Concepts for NASA emergency medical operations also include scenarios where concentrated oxygen must be provided to an ill or injured crew member. The fire hazard greatly increases when medical treatments such as defibrillation or cauterization are performed in the locally-enriched oxygen atmosphere around the patient's head and torso.

For future space missions, NASA is planning to increase the oxygen concentration and reduce the total pressure of the atmosphere in the Orion crew exploration vehicle, the Altair lander, and future lunar habitats [2]. They are being designed to operate from 21% oxygen at 14.7 psia up to 34% oxygen at 8 psia along the normoxic curve (approximately constant partial pressure of oxygen). The transition from higher pressure, lower oxygen concentrations to lower pressure, higher oxygen concentrations will occur as exploration needs change from ISS crew exchange to lunar missions. This atmosphere has the advantages of requiring less consumable mass of inert gas (N₂) to offset leakage, lowering vehicle internal pressures to reduce structural requirements, and shortening the pre-breathe time required to purge nitrogen from the bloodstream before Extra Vehicular Activity (EVA).

However, an enriched oxygen atmosphere also has a significant disadvantage – increased flammability of materials. One of the major lessons learned from the Apollo 1 fire is that it is impossible to eliminate all ignition sources [3], so fire prevention is achieved in spacecraft through material control and the use of fire resistant materials. Since Skylab, the Space Shuttle and the International Space Station (ISS) have operated at normal sea-level conditions (air, 21% oxygen/79% nitrogen by volume at 14.7 psia total pressure) except for pre-EVA activities when oxygen levels are increased for a short period of time to 30% oxygen while the total pressure is lowered to 10.2 psia. Many of the materials now used in the Shuttle or on ISS are therefore only tested and rated to 30% oxygen at 10.2 psia. In addition, the quantity of waived material has grown over the years, such as crew clothing, COTS equipment, etc.

The local oxygen concentration around an astronaut can be even further elevated during emergencies where oxygen masks are used, such as fire, intensive care medical treatment, or toxic spills. For every breath of pure oxygen breathed in, the exhaled breath still contains ~ 95% of the oxygen. This creates an environment of increased oxygen near the head and chest. Since hair is marginally flammable even in air, any ignition source (spark, hot surface, etc.) could create a potentially life-threatening situation for the astronaut.

Hair is a sensitive topic, since it is a significant part of personal image. Hair styles worn on Earth may not be the best for space, but due to the generally short mission duration, most astronauts do not change their hair style significantly during missions. Haircuts are needed on longer missions, as shown in Figure 1. However, in the elevated oxygen concentrations expected in future long duration exploration missions, this liberal approach may need to be revisited, possibly including dense chest hair in the event of a medical emergency.

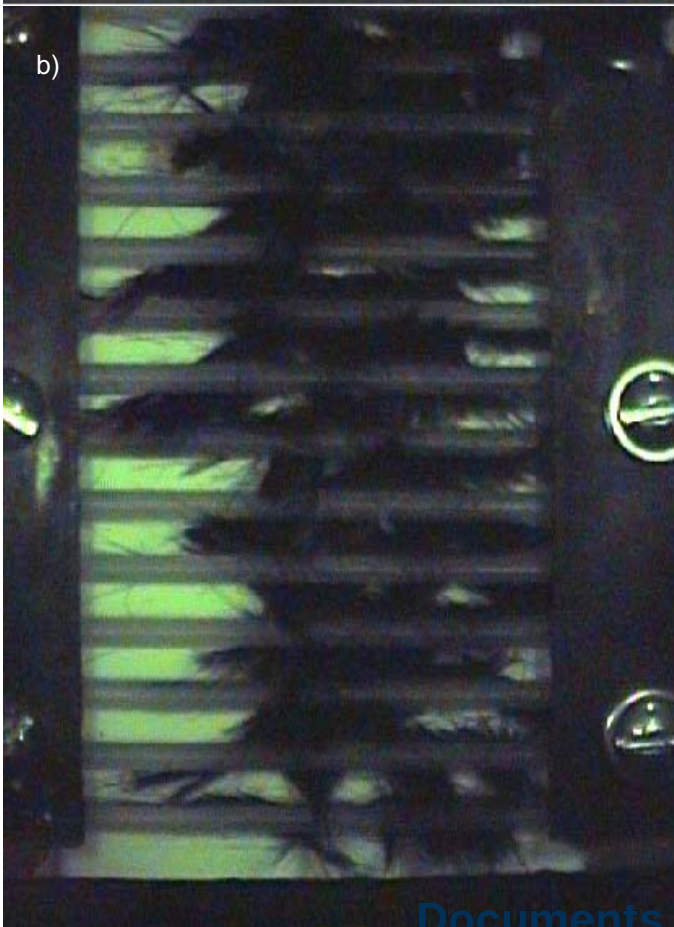
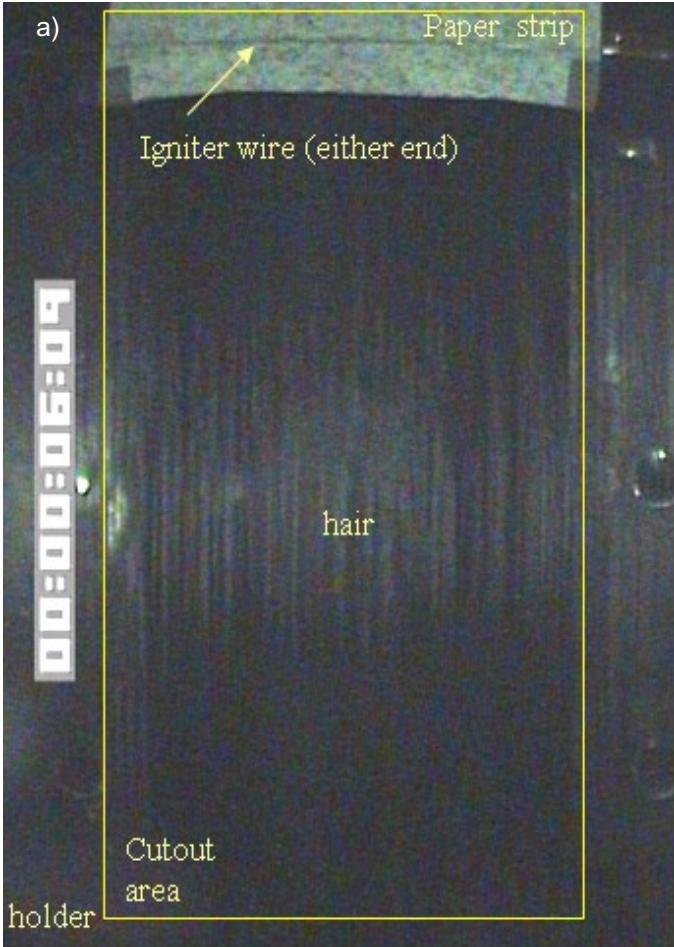


Figure 2: Hair in sample holder. a) long strands parallel to the flow direction (up), b) short hair held in comb-like holder.



Figure 1: ISS Expedition 5 Commander Valery Korzun cuts the hair of astronaut Peggy Whitson, during their 2002 tour of duty aboard the space station. Whitson holds the vacuum device that collects the free-floating freshly cut hair.