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FROM STRENGTH TO LEAKAGE: EXTENSIVE MECHANICAL TESTING OF A NOVEL ULTRA-LIGHT MEMBRANE SMALL INDOOR AIRSHIP

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ABSTRACT

Small aerial vehicles are increasingly utilized for indoor applications such as surveillance, inspection, exploration, and telepresence, particularly in confined and cluttered spaces like industrial facilities, warehouses, and public venues. However, their limited autonomy remains a critical barrier for tasks requiring sustained operations. Indoor airships, or blimps, provide substantially greater flight endurance compared to multiposters but face significant challenges due to constraints on the volume of lighter-than-air gas they can contain while maintaining maneuverability. For airships with volumes around one cubic meter, payload capacity is severely restricted as much of the available lift is consumed by the weight of the envelope material. Existing commercial envelope materials fail to achieve an optimal balance of weight, durability, and gas retention at that scale. Metalized PET (Mylar) offers excellent helium retention but is brittle and prone to tearing, while polyurethane (PU) provides better durability but incurs higher weight and helium leakage. This study proposes low-density polyethylene (LDPE) as a lighter, more tear-resistant alternative. To mitigate LDPE's helium permeability, attributed to its amorphous polymer structure, a fluoro-siloxane-based sol-gel coating was applied, enhancing its gas barrier properties. Experimental evaluations revealed that coated LDPE films exhibited 138.14% greater tear resistance than Mylar and 9.13% greater tear resistance than PU, alongside a 35% weight reduction compared to PU. The helium leakage rate for coated LDPE was measured at 1.7 g/h, significantly lower than the 4.2 g/h observed for PU, indicating improved helium retention. Additionally, the sol-gel coating imparted superior hydrophobicity, reducing moisture absorption and ensuring reliable performance in humid environments. To validate its performance in real-world scenarios, a large cylindrical airship (0.85 m^3) featuring a coated LDPE envelope was fabricated and tested alongside PU-based alternatives in a semi-autonomous 3D mapping mission within Montreal's Saint-Leonard Cave. The LDPE envelope demonstrated superior durability, extended operational endurance, and enhanced resistance to environmental factors, surpassing its PU counterpart in both performance and weight-efficiency. This work addresses a critical gap in lighter-than-air material development, enabling extended flight durations, reduced helium loss, and greater reliability for indoor applications such as surveillance, exploration, and industrial inspection.