New results about compatibility conditions and solutions for a model of inerted gas in a vented fuel tank ullage

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Abstract. The fire safety concerns are of paramount relevance in fuel tank designs. One of the most extended solutions to decrease the fuel tank flammability is the inerting system, that has been extensively used in aircraft fuel tanks. The intention is to provide new results about the compatibility conditions in vented fuel tanks, to ensure that the forced convection does not detrimentally impact the formation of an inerted ullage. In addition, we provide some new solutions that complement the existing literature together with a validation based on data from a real flight test.

Introduction

A Boeing 747-131 owned by Trans World Airlines crashed on July, 1996 over the Atlantic Ocean. One of the design solutions proposed, to avoid similar accidents, consisted on the removal of the oxygen and the replacement by nitrogen in the fuel tank ullage [1]. This solution, known as Inerting System, is currently well implemented in civil and military aircrafts. In [2], a model is constructed with a mass balance. In [3], the authors analyze a PDE to describe the concentration of fuel vapors. In [4], the three main physical ideas related with the gases interaction were introduced: diffusion, reaction and forced convection. At the moment of such a model proposal, it was not clear what conditions are required so that the forced convection, in vented fuel tanks, does not lead to impact the effective diffusive mechanisms of the inerted gas to reach all the tank zones.

Results and discussions

The proposed model for the interaction between oxygen (Θ) and nitrogen (N) is ([4]):

$$N_t = \Delta N + a \cdot \nabla N - \Theta^n (N - r); \; \Theta_t = \Delta \Theta + a \cdot \nabla \Theta - N^m \, \Theta; \; N_0(x), \Theta_0(x) \in L^1_{loc}(\mathbb{R}^3) \cap L^\infty(\mathbb{R}^3),$$

where $r \geq \max_{x \in \mathbb{R}^3}\{N_0(x)\}$, a is the vented convection vector and $n, m \in (0,1)$ two calibrated constants. Given the solution $(N, \Theta) \in C^{2+\gamma, \, 1+\gamma/2}(\mathbb{R}^3 \times (0,T))$, $\gamma > 0$ with $\Theta_t \leq 0$ and $N_t \geq 0$, two new compatibility conditions, involving the initial distributions, are shown to ensure that the reaction and diffusive terms predominate over the vented convection: $\int_{\mathbb{R}^N} N_0^m \geq |a| \Theta_0, \quad \Theta_0^n \geq 2a \cdot \nabla N_0$. Based on the data obtained from [4], the new compatibility conditions are indeed met. The air is formed of 80% of nitrogen ($N_0 = 0.8$) and 20% of oxygen ($\Theta_0 = 0.2$). Then $\nabla N_0 = 0$, such that: $\Theta_0^n \geq 2a \cdot \nabla N_0 = 0$. Note that $\Theta_0^n = 0.2^{0.586} = 0.389$ (refer to [4] for the value of n). The second compatibility condition is achieved as $0.389 > 0$. Considering the first compatibility condition: $\int_{tank} N_0^m \, dV = 0.80^{0.025} \, V_{tank} = 0.80^{0.025} \cdot 1.5 \cdot 6 \cdot 6.5 = 58.17$. The volume of the tank is the typical for a Boeing 747 (see again [4] for further details). We have $|a| \, \Theta_0 = 0.0125 \cdot 0.2 = 0.0025$ (for the value of $|a|$ refer to [4]). Then: $\int_{tank} N_0^m \, dV > |a| \, \Theta_0$. We should notice that the compatibility conditions are met. In addition, the following new flat solutions have been obtained: $N(t) = \|N(x,0)\|_p + \theta t$ and $\Theta(t) = \|\Theta(x,0)\|_p - \frac{1}{\theta(m+1)}(\|N(x,0)\|_r + \theta t)^{m+1}$, where θ is the minimum level of oxygen concentration (usually $\theta \sim 0.05$, see [2]) and $p > 0$, typically $p = 1$ for a finite mass distribution. The solutions are obtained for a discrete time set of amplitude: $T = \frac{(\|\Theta(x,0)\|_r - \theta^{1/n})^{\frac{1}{m+1}} \; (\theta(m+1))^{\frac{1}{m+1}} - \|N(x,0)\|_r}{\theta}$.

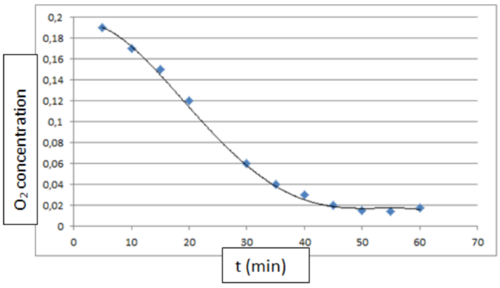

Figure 1: The black line represents the oxygen concentration evolution in steps of amplitude T.

References

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