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# Design and Analysis on the Fire Prevention System for Space Launch Vehicle during the Flight

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## Abstract

Fire safety for space launch vehicle is very important issue and should be guaranteed at the nearly all the phases from launch preparation to flight. In the space launch vehicle system, fire safety can be secured by passive and active methods. The method including material selection regulations and leak rate controlling is categorized in the passive one. On the other hand active method adopts purging inert gas into the compartment of launch vehicle and thus it can reduce the concentration of flammable gases and expel them form the compartment. Normally this can be assured without difficulty at the launch pad with ground system. However, during the flight it is not easy to obtain and needs some additional system such as fire prevention system. In this paper, design for the fire prevention system for space launch vehicle during the flight is explained and the analysis is described. As a result, fire prevention system is worth introducing for space launch vehicle in terms of reliable fire safety during the flight.

## 1. Introduction

Space launch vehicle using liquid propellants is highly at risk of fire and explosion, and therefore require active techniques and passive management procedures to remove the hazards. Active techniques reduce the concentration of flammable fuel gases that can cause fire and explosion. Preventing leakage of fuels is the passive management and it should be, but in reality, some leakage is inevitable. Therefore, it is necessary to actively reduce the concentration of flammable gases to make it impossible to ignite or explode. To this end, the non-flammable gas such as nitrogen or helium is used for the system and such system is called a fire safety device.

Normally, Fire safety systems are classified according to the time of operation (related to launch operation) of the fire safety system in the launch vehicle. The system that supplies the fire safety gas during the launch standby from the launch pad is called the thermal control/fire safety system. The system to supply fire safety gas into the vehicle during the flight is called the fire prevention system. Both are active fire safety techniques. Almost all the launch vehicle adopt the thermal control/fire safety system whereas application of fire prevention system depends on the vehicle. In other countries cases, this system was applied to the atlas launch vehicle [1] and the used gas is helium. In this case, the pneumatic purge was switched from the ground to fire safety system at T-9.9 s by enabling blowdown of the airborne helium purge bottle. The purge then continued until the helium supply was depleted, by which time the vehicle had cleared the atmosphere

In KSLV-II, for more safety environment, the fire prevention system will be applied. The purpose of this paper is to introduce the design of fire prevention system of KSLV-II and analyse its capability of supplying gas into the compartment as the required time conservatively. The term compartment as used herein refers to a space inside the launch vehicle body, which is adjacent to the propellant tank, while being mounted with electronic mountings therein. In the analysis we will examine the environmental changes inside the compartment especially for the pressure change which is important design parameter.

For the system analysis the one-dimensional fluid system analysis software, flowmaster [2], was used. In this analysis we can check the ability of fire prevention system to supply the inert gas for the required time and to keep the pressure inside the compartment positive. Another important function of the fire prevention system is to check how it well discharge the hazardous or flammable gases generated from the propulsion system to the outside. In order to verify this ability well known software fluent [3] is adopted. With these analysis results the system design will be modified

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and later its demonstration test model also will be manufactured and tested. Thus these analysis data are the design input for the future real model.

## 2. Fire prevention system design and modelling for analysis

Fire prevention system is designed for the purpose of fire safe during the flight thus it can blow out the hazardous gases that could be leaked from the propellant lines, valves etc. and it also keeps the pressure inside compartment positive compared to the outside[4, 5]. With this requirement the system can be composed of pressure bottle that can contain the high pressure gas, valves for operation on time, pipes through which the gas flows, gas distribution manifold and some sensors. And for gas venting, the vent valve is attached on the compartment skin.

Another critical design parameter is that the system can keep the pressure inside compartment positive until the required time after the vehicle lift-off. This capability prevent the outside hot gas from penetrating through the gap if exists. The hot gas passing through the gap can be the ignition source for flammable gases and cause hot temperature environment. Considering these requirement, system was designed and its components were selected at first. And next for the designed system, pneumatic analysis was done to check its feasibility.

### 2.1 Fire prevention system design

Figure 1 shows the overall schematic diagram and pictorial view of flow inside the compartment where main engine is installed. As mentioned before, the inert gas is stored in the bottle with high pressure for getting more mass. The inert gas candidates are helium, nitrogen, and Freon but taking the environment regulation and handling, detection characteristics into account, nitrogen is selected for the gas. As an operation valve, pyro type one is selected due to its high reliability and one-time working. But for redundancy two pyro valves are used simultaneously thus only one valve is enough for the normal operation. And next flow control orifice is designed for the required operation time and maximum flow rate. Finally the gas distribution manifold is designed with ring type pipe having several holes drilled on it. This ring type manifold can make such broad gas flow inside the compartment that there is no flow dead zone. It is very important issue in the view of fire safe. In Figure 1, TS means temperature sensor, PS means pressure sensor, MF means manifold, dPF1 means orifice.

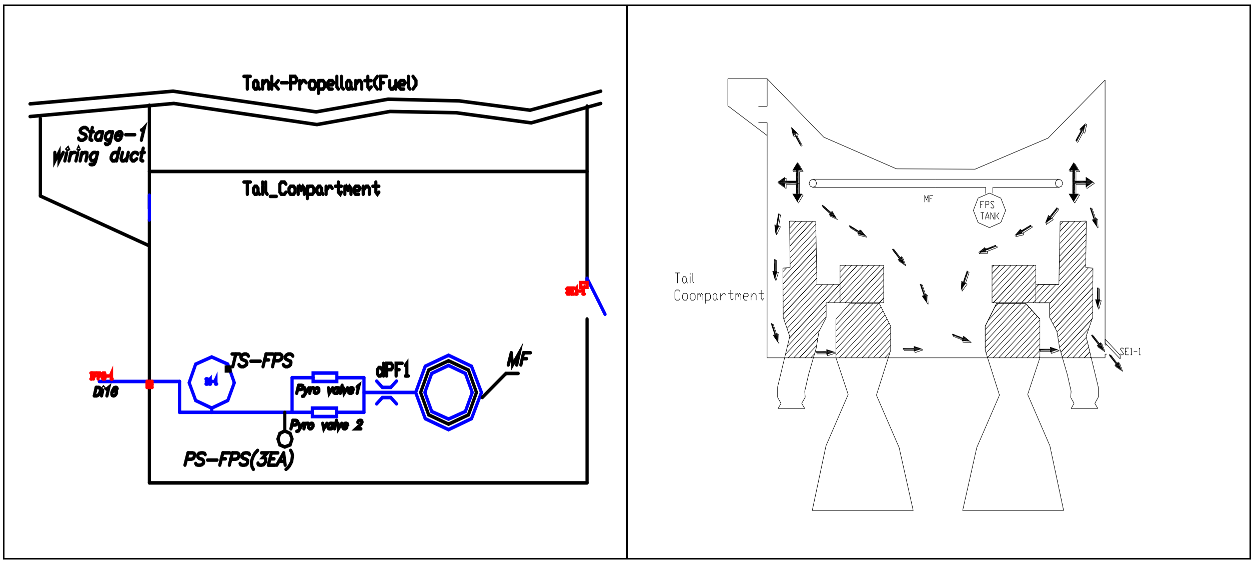


Figure 1: Schematic diagram and inside gas flow view of fire prevention system

### 2.2 System modelling for analysis

For the analysis, one dimensional thermal and fluid analysis software flowmaster is adopted and thus all the design parts should be modelled with program. In order of precedence, the high pressure bottle is simulated with accumulator model of software. The equation used to simulate the gas condition inside the high-pressure tank is the equation of state and the correlation between temperature and pressure is considered. Since the pressure is high and the final

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operation temperature may be low, the real gas model RKS state equation is used [6]. Heat transfer between tank and gas was not considered, i.e., adiabatic condition is applied. In view of temperature, this condition can cause lower final value than the real one.

One-dimensional continuity equation, momentum and energy equations are applied to simulate the unsteady one-dimensional compressible flow in the piping. In order to derive the pressure drop coefficient due to the surface friction inside the pipe, the formula of Colebrook-White, which optimizes the values of the Moody Chart, is applied, and the roughness of the piping is chosen as 0.025mm which is the roughness value of the newly manufactured pipe [7]. The heat transfer inside the piping is mainly due to the heat transfer by the gas inside the piping but like the bottle case, adiabatic condition is applied also. This assumption is somewhat reasonable because the length of piping is relatively short. Fire prevention system regulates the flow rate through the orifice while simultaneously lowering the pressure value at the manifold to within the required range.

The orifice flow analysis is the most important process and can be obtained by iteratively carrying out the process of finding several important parameters. During the iteration, the initial shrinkage factor and loss factor are corrected to obtain the data from the incompressible flow data and then applied to the compressible flow, which is obtained by calculating the shrinkage coefficient and the loss coefficient in the compressible orifice flow. When the final corrected loss factor Kc is derived. This procedure is summarized as below [8];

- At first calculating the contraction coefficient, Cc
- Calculating the loss coefficient, Ki , to this point, incompressible data is used
- Obtaining the apparent area ratio
- Getting the discharge coefficient, Cd
- For Cc, compensating compressible effect, CCc
- Modified loss coefficient of Kc is re-calculated
- Pressure and mass flow rate equation are derived

The pressure and mass flow rate can be obtained using the pressure and mass flow equations as follows [8].

$$\frac{P_{t2}}{P_{t1}} = 1 - K_c\left(1 - \frac{P_{s1}}{P_{t1}}\right) \;\&\; \frac{P_t}{P} = \left[1 + \frac{(\gamma-1)M^2}{2}\right]^{\frac{\gamma}{\gamma-1}} \quad \textbf{(1)}$$

$$\frac{\dot{m}(ZRT_t)^{1/2}}{AP_t} = \gamma^{1/2} M \Big/ \left[1 + \frac{(\gamma-1)M^2}{2}\right]^{\frac{(\gamma+1)}{2(\gamma-1)}} \quad \textbf{(2)}$$

where $\dot{m}$ is mass flow rate, Kc is orifice loss coefficient for compressible, $T_t$ is total temperature, $P_t$ is total pressure, A is flow area, M is Mach number, R is gas constant, Z is compressible factor, $P_s$ is static pressure, $\gamma$ is specific heat ratio. Free volume model of flowmaster is applied for the compartment. This model like accumulator model provides physical information about the compartment, temperature and pressure correlations and gas mixing at the inlet and outlet. A compressible check valve model was applied to the vent valve. The performance curve data derived from the experimental results having the form of flow rate versus differential pressure are incorporated into the model. With this analysis model, we can check the ability of the fire prevention system to supply the gas for the required time and whether the pressure inside the compartment is positive or not. In Figure 2, flowmaster analysis model scheme is shown with the some results.

Another important issue is to verify the capability to discharge the hazardous or flammable gases generated from propulsion system. In order to test how this system can discharge the flammable gases, we set the imaginary two cases like below;

Table 1: Analysis case for checking the discharging capability

| | **Case 1** | **Case 2** |
|---|---|---|
| System application | No | Yes |
| Flammable gas leak rate | 0.01 kg/hr | 0.1 kg/hr |

Analysis domain: axis-symmetric cylinder shape

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For simple but reasonable study, the compartment is set to be cylinder shape and the inert gas inlet position is in the center of it while the flammable gas generates at the wall side. The analysis was done with transient, axis-symmetric conditions in fluent. The final result is obtained in the form of flammable gas concentration distribution so the data are rearranged with discretization. The discretization proceeds when the concentration value is smaller than ‘0.5’ it is regarded as ‘0’, and when it is larger than 0.5, it is regarded as ‘1’. ‘1’ is judged that it exists in the space but ‘0’ is judged that it is discharged. In this way, we can get the final state of species concentration which shows the ability of discharging the flammable gas.

## 3. Analysis results and discussion

### 3.1 Gas supplying and pressure inside the compartment

In Figure 2, the flowmaster analysis model is shown and all the analysis models can be matched with the components of fire prevention system with comparing to the schematic diagram or drawing in Figure 1. In this model, there is not the pyro valves because the system analysis is done right after the pyro valve operation. And in this case for the orifice model sharped edge one is adopted. In this analysis the outside environment condition is set from the standard atmosphere data [9].

What we only focus at this analysis are the gas supplying time and pressure inside the compartment with designed stored gas pressure and volume. As can be seen from the graph, the initial stored inert gas pressure is about 22 MPa with volume of 0.066 $m^3$. After the 90 s operation of fire prevention system, the stored gas pressure remains above the 0.4 MPa and the pressure inside the compartment is about 13 kPa that is much higher value than that of the outside atmosphere. Therefore it is confirmed that designed gas volume and pressure with orifice are appropriate for the input of demonstration model. And later for more accurate analysis, it is necessary to include the heat transfer between the high pressure tank and the gas, and the heat transfer between gas and the compartment.

In the future the pyro operation time will be fixed. Then the environment such as temperature and pressure inside the compartment varies with the space launch vehicle altitude and fire prevention system operation because there can be an abrupt pressure increasing inside the compartment. Thus another simulation for that situation should be done with considering the demonstration model test results. That case, pyro valves are to be modelled and valve control parameter like controller is also adopted properly.

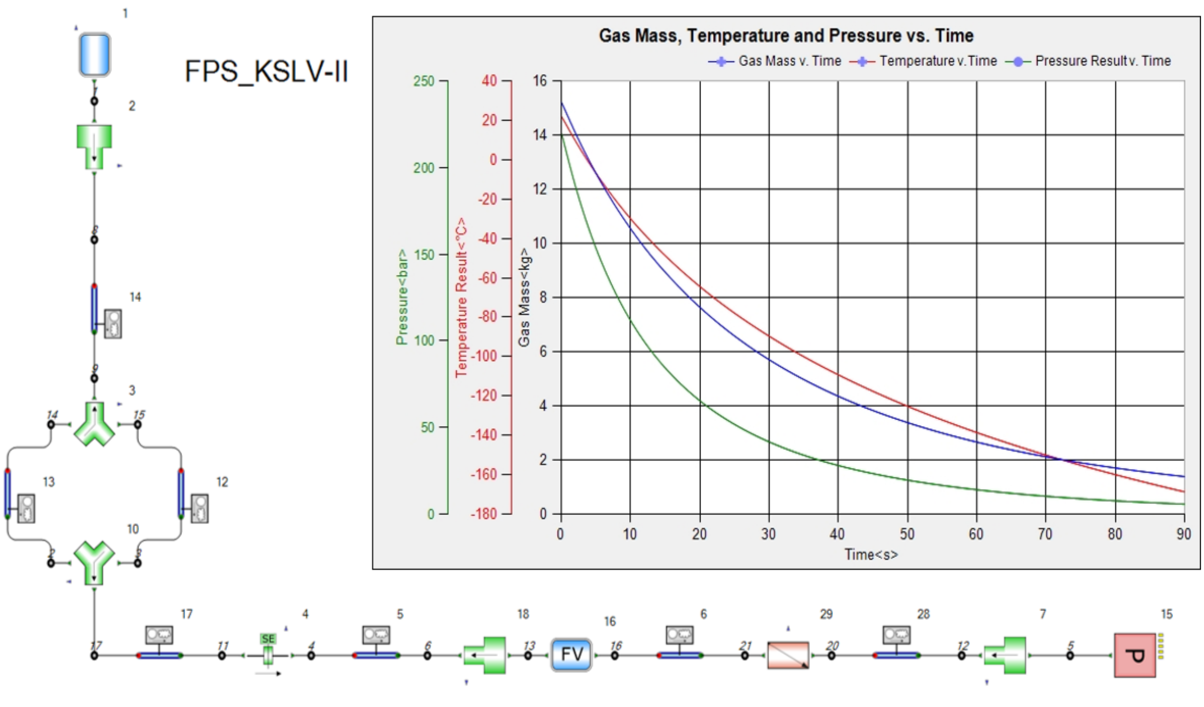


Figure 2: Fire prevention system analysis scheme and the results

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### 3.2 Flammable gas discharging capability

In Figure 3, the analysis results are shown. The left result which is for CASE I has locally high gas concentration at the side wall. After the 45 s the gas doesn't diffuse and dissipate. Instead, it looks stay nearby. However, the right result which is for CASE II has diluted gas concentration all the domain within 35 s that is shorter than that of left CASE I. Moreover the leakage rates of the two case is different by order of magnitude. The leak rate of CASE II is much larger. As a result, the results show that the difference in the flammable gas concentration distribution in the compartment is evident by the presence or absence of the fire prevention system when the flammable gas leakage occurs. Thus it is confirmed that fire prevention system has very powerful ability to discharge the hazardous or combustible gases.

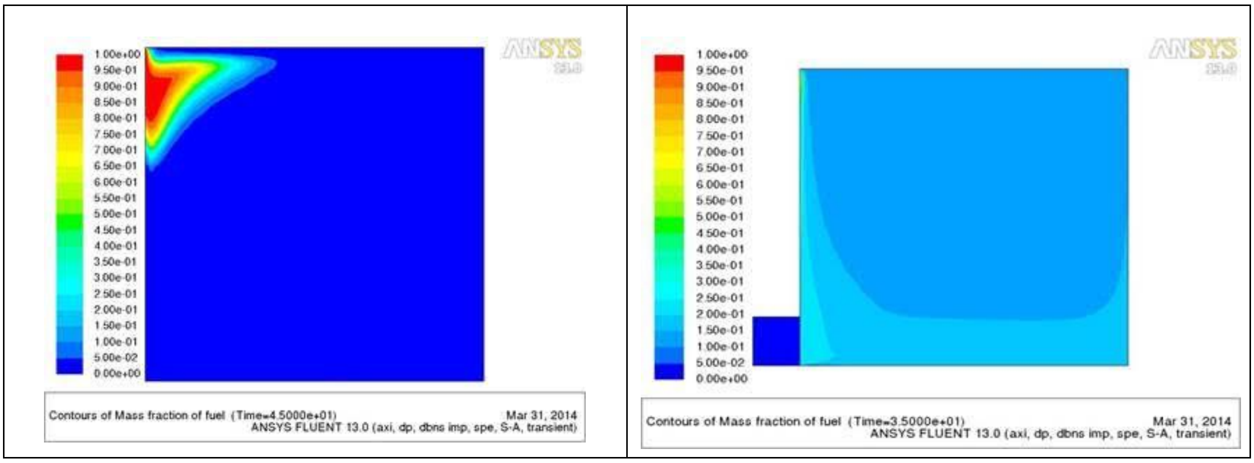


Figure 3: Flammble gas concentration distribution results with or without the fire prevention system operation, left- CASE I & right- CASE II

## References

[1] NASA NRC, 1968. Atlas-Centaur Flight Performance for Surveyor Mission B. *NASA TM X-1616.*
[2] https://www.mentor.com/products/mechanical/flomaster/flomaster.
[3] http://www.ansys.com/Products/Fluids/ANSYS-Fluent.
[4] J. Y. Ko and I. Kim, 2013. Quantitative Analysis for KSLV-I Fire Prevention System during the Flight. In: *2013 KSPE Spring Conference.*
[5] J. Y. Ko and H. Ok, 2015. Analysis on the Fire Prevention System of Launch Vehicle and the Pressure Variation inside Compartment. In: *2015 KSPE Spring Conference.*
[6] W.Z. Black and J.G. Hartley, 1996. Thermodynamics. *Harper Collins College Publishers, 3rd edition.*
[7] F. M. White, 1999. Fluid mechanics. McGraw-Hill, 4th edition.
[8] D.S. Miller, 1990. Internal flow systems. *BHRA, 2nd edition*.
[9] C.G. Justus and D.L. Johnson, 1999. The NASA/MSFC global reference atmospheric model: 1999 version (GRAM-99), *NASA TM-1999-209630*.