Simulation of Gravity Feed Oil for Aeroplane

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Abstract

The traditional method to calculate the gravity feed is to assume that only one tank in fuel system supplies the needed fuel to the engine, and then calculated for the single branch. Actually, all fuel tanks compete for supplying oil. Our method takes into consideration all fuel tanks and therefore, we believe, our method is intrinsically superior to traditional methods and is closer to understanding the real seriousness of the oil supply situation. Firstly, the thesis gives the mathematical model for fuel flow pipe, pump, check valve and the simulation model for fuel tank. On the basis of flow network theory and time difference method, we established a new calculation method for gravity feed oil of aeroplane fuel system, secondly. This model can solve the multiple-branch and transient process simulation of gravity feed oil. Finally, we give a numerical example for a certain type of aircraft, achieved the variations of oil level and flow mass per second of each oil tanks. In addition, we also obtained the variations of the oil pressure of the engine inlet, and predicted the maximum time that the aeroplane could fly safely under gravity feed. These variations show that our proposed method of calculations is satisfactory.

Nomenclature

Q	volumetric flow rate
P	pressure from a datum at certain points
P_s	air pressure in fuel tank
γ	specific gravity of the fluid
g	acceleration of gravity
ρ	density of fuel
Z	elevation from a datum at certain points
L	pipe diameter
D	pipe length
f	friction factor for pipes
K	dimensionless experimental coefficient accounting for head losses
h	height fuel level from the bottom of tanks
$A(h)$	tank cross-sectional area at h
Re	Reynolds number
μ	dynamic viscosity of fluid
$P_{in,out}$	pressure at the inlet and outlet of elements
V	velocity of fluid
C	Hazen-William constant
ξ	resistance characteristic constant of pump
a	characteristic constant of check value
P_c	crack pressure of check value

Introduction

The function of fuel system of aircraft is to store fuel and supply it to the engine under certain flow rate and pressure continuously [1,2]. Generally, it has two different ways for fuel transfer, the simplest one is by gravity [1,2], and another is by pumps. But when flying, it exists the possibility that all the pumps stop working under some situation, such as electrical and mechanical accident. So the simplest method changes to the vital one. The study of gravity feed oil is also important.

Fuel transfer system is a system, which comprises many fuel tanks and much complex pipelines. The traditional method to calculate the gravity feed is to assume that only one tank in fuel system supplies the needed fuel to the engine, and then calculated for the single branch. Actually, gravity feed oil is a transient process. The oil level in fuel tanks decreases when fuel transferring and the ability of one fuel tank for oil supply decreases also. With this changes, there might have several fuel tanks supplies fuel simultaneously. Thus the oil supply network is a complex system in which may have many branches. The key problem to calculate gravity feed oil is the simulation of multiple-branch and transient process. The paper established a new calculation method for gravity feed oil of aeroplane fuel system. This model can solve the multiple-branch and transient process simulation of gravity feed oil. Finally, we give a numerical example for a certain type of aircraft.

Gravity feed analysis

The fuel transfer system of a certain aircraft is composed of fuel tanks, fuel pumps, pipes, check valves and other common flow resistance components. When fuel transfers under gravity, the oil flows spontaneously through the oil pump and the check valve. Here, the oil pump is stop operating, which is considered as a resistance element specially. The function of the check valve is to prevent the oil backward flow between fuel tanks.

Fuel tank supplies oil according to its ability of gravity feed oil. There might have some factors effect the ability, which include the air pressure in tanks, P_s, the gravitational potential energy of oil and the resistance of fuel offer pipeline, h_w. The pressure in tanks is related to vent system of aircraft and approximately equal in different tanks. The gravitational potential energy of oil changes with the oil level, h, and the elevation from the bottom of tank to engine inlet, Z. Figure 1 is a schematic diagram of gravity feed oil.

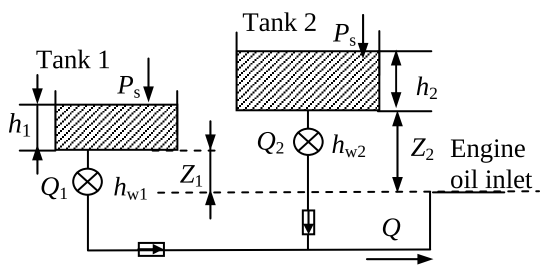

Fig.1 The schematic diagram of gravity feed oil

Theory

Flow network theory

In order to decide the flow rate and pressure drop through the flow network, first, the theory of mass conservation may be imposed at each junction of the flow network. Therefore, the algebraic summation of all flow entering a junction is zero [3~5]. For the incompressible flow, at a node, the continuity equation is

$$\sum_{i=1}^{n} Q_i = 0 \tag{1}$$

Second, the continuity of energy per unit mass may be applied along the same streamline. The energy potential between two nodes in certain pipe is equal. For the incompressible flow on the same streamline, the energy balance equation [6] is

$$\frac{P_a}{\gamma} + \frac{V_a^2}{2g} + Z_a = \frac{P_b}{\gamma} + \frac{V_b^2}{2g} + Z_b + h_w \tag{2}$$

Where, P_a, P_b, and V_a, V_b and Z_a, Z_b represent pressure, velocity and elevation from a datum at certain points, a and b. h_w is frictional head loss. γ is specific gravity of the fluid, g is acceleration of gravity.

Element Model

(1) Pipe flow

For the incompressible flow, the pressure drop through a pipe is induced by the energy Equation (2).

$$P_a - P_b = \rho f(Q,D) \frac{8Q^2}{\pi^2 D^4} \left\{ \frac{L}{D} + \frac{K}{f(Q,D)} \right\} + \gamma (Z_b - Z_a) \tag{3}$$

Where, K is the dimensionless experimental coefficient accounting for head losses in bend, elbows etc. For the general elbow, K = 0.5, and the T-type joint, K = 1.0[6]. ρ is the density of fluid. Q is volumetric flow rate. f is a friction factor for pipes of circular cross section. The friction factor for turbulent flow can be decided by Reynolds number(Re), velocity(V) and Hazen-William constant(C) [7].

1) laminar flow, $\mathrm{Re} \le 2000$

$$f(Q,D) = \frac{64}{\mathrm{Re}} \tag{4}$$

2) turbulent flow, $\mathrm{Re}>2000$

$$f(Q,D) = 1304.56 \frac{V^{0.0184}}{C^{1.852}\, \mathrm{Re}^{0.1664}} \tag{5}$$

Where, Re can be expressed by $4\rho Q / \pi \mu D$. μ is dynamic viscosity of fuel.

(2) Oil Pump flow

The oil pump is stop operating when fuel transferring under gravity, and it is considered as a local resistance element. The relationship between flow rate and pressure difference can be expressed by Equation (6).

$$P_{in} - P_{out} = \xi Q^2 \tag{6}$$

Where, ξ is constant that decide by resistance curve of oil pump.

(3) Check valve flow

The function of the check valves is to prevent the oil backward flow between two fuel tanks. The valve remains completely closed until the positive pressure differential exceeds the crack pressure. The relationship between flow rate and pressure difference can be expressed by Equation (7).

$$P_{in} - P_{out} = aQ^2 + P_c \tag{7}$$

Where, a is a constant that decide by characteristic curve which obtained by experimentation, and P_c is the crack pressure.

(4) Fuel tank model

The illustration of model of fuel tank is show in Figure 2. Where, Z is the tank's parameter of location, P_s is air pressure in fuel tank, and h is the fuel level. Because of Z is constant when the fuel system of aircraft has been design finished, *h* is the only variable that effects the gravitational potential energy of oil and further effects the ability of gravity feed of fuel tank. We presented the curve for fuel tank, which show the relationship between cross-section area, *A*(*h*) and fuel level, *h*. These curves could be used to simulate the changes of oil level in gravity feed process which detailed in the next part. The curves of the five fuel tank for one aeroplane are illustrated in

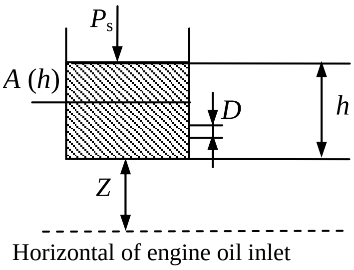

Fig.2 Model of fuel tank

Figure 3~7.

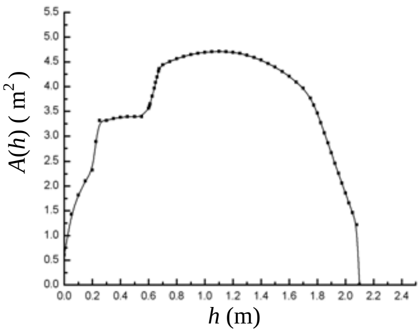

Fig.3 The relation curve for fuel tank 1

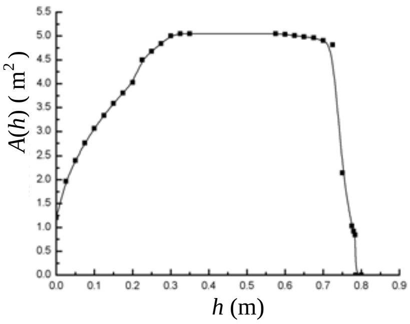

Fig.4 The relation curve for fuel tank 2

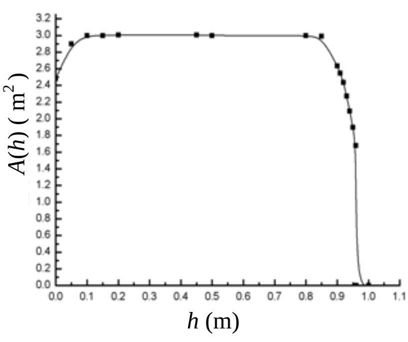

Fig.5 The relation curve for fuel tank 3

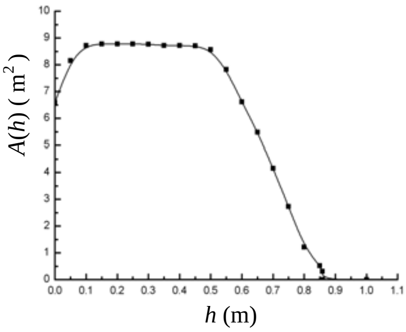

Fig.6 The relation curve for fuel tank 4

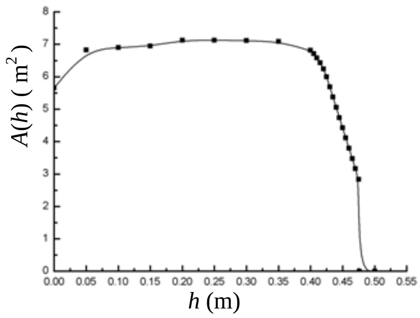

Fig.7 The relation curve for fuel tank 5

Transient Process Simulation

This study used the time difference method to simulate the transient process. Based on this method, we divided the whole process of gravity feed into many small time sections, Δt_1, Δt_2, … Δt_n. In one time interval Δt_i, it assumed that the whole flow process is steady-state, and the oil flow rate of each fuel tank is considered as a constant.

On the basis of the difference method, the transient process is simulated below:

1) Define the oil level of each fuel tank, h_i^t, at the beginning time, $t=t_0$, of gravity feed.
2) Define the boundary condition.
3) Network calculation

Calculation for the whole fuel transfer system using flow network theory, obtain the flow rate of each fuel tank, Q_i^t, and the pressure distribution in flow system.

4) Using the fuel tank model to calculate the new oil level of each fuel tank, $h_i^{t+\Delta t}$.

$$\begin{cases} \Delta h_i^t = \dfrac{Q_i^t \cdot \Delta t}{A(h_i^t)} \\ h_i^{t+\Delta t} = h_i^t - \Delta h_i^t \end{cases} \tag{8}$$

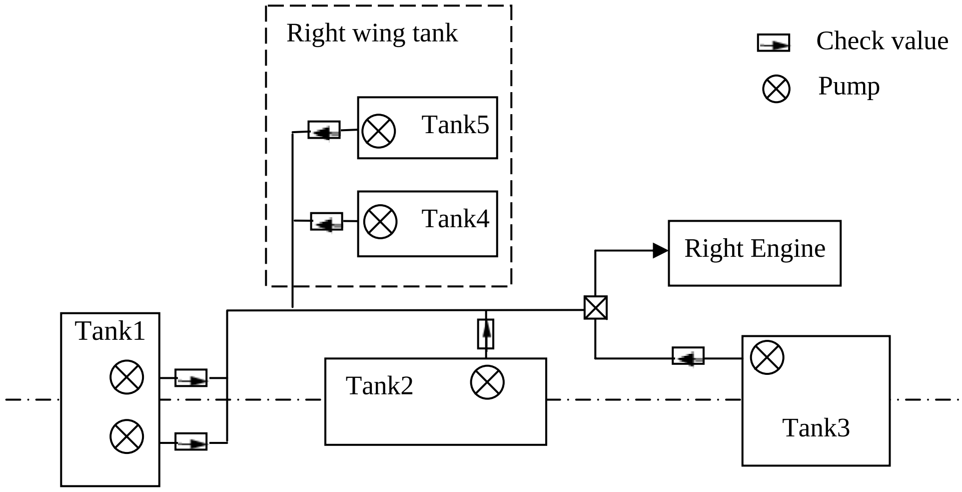

Fig.8 Right fuel transfer system for one aircraft

5) Define the new oil level of each fuel tank when $t=t+\triangle t$, $h_i^{t+\Delta t}$.

Repeat step 3) to step 5), the whole transient process of gravity feed could be simulated.

Numerical

Based on the established method, we calculated the gravity feed for one certain type of aircraft. The aircraft has two (right and left) fuel transfer system, the right system showed in figure 8 transferring fuel for the right engine and the left providing fuel for the left engine, the two system also can supply fuel to one engine simultaneity in addition .

As show in figure 8, the right fuel transfer system has five fuel tanks, and the tank 4 and tank 5 assembled in the wing, the check values which installed in the fuel transfer pipes to prevent the oil backward flow between fuel tanks.

The right system gravity feed has been simulated in this section with the flight condition: flight height is 7km and the engine is 0.5 rated condition. The calculation boundary condition for network is the air pressure in each fuel tanks (approximately equal the atmospheric pressure at 7km) and the fuel flow rate to the engine which is 2800kg/h (0.000997m^3/s).

We also should give the fuel level in each fuel tanks when calculation. All the fuel tank is assumed filled at the beginning of the calculation and the fuel level for the five fuel tank could be obtained from the tank relation curves showed in Figure 3~7.

In the simulation, we obtained the variation of oil level in each fuel tank, the fuel flow rate for each fuel tank and the variation of pressure at the engine inlet. The calculate results are showed in figure 9~11.

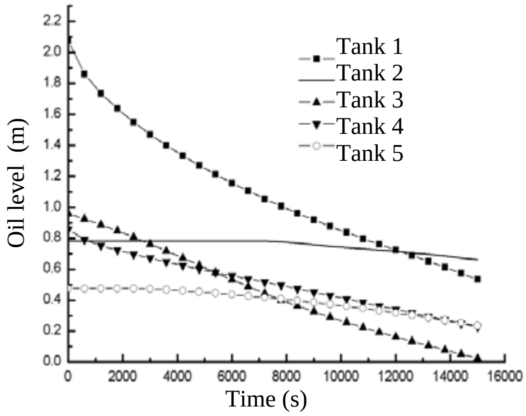

Fig.9 Variation of oil level in each fuel tank

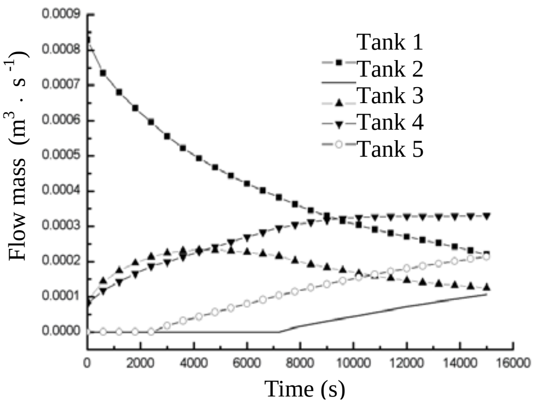

Fig.10 Variation of flow mass of each fuel tank

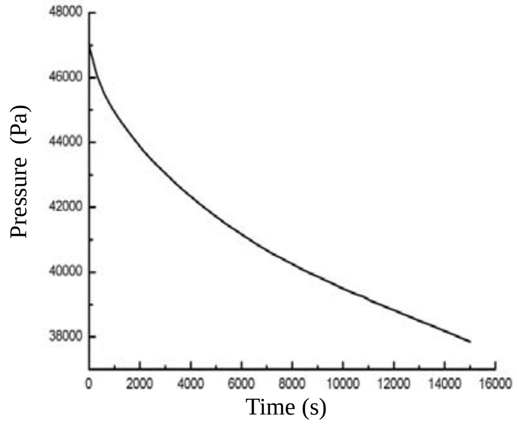

Fig.11 Changes of the fuel pressure at engine inlet

Analysis

Figure 9 and Figure 10 give respectively the variations of oil level and flow rate per second of each five oil tanks within a period of 16000 seconds. Figure 11 shows the changes of oil pressure in engine inlet.

As show in Figure 9 and Figure 10, the tank 1, tank 3 and tank 4 all supplies fuel to the engine at different flow rate at the beginning of gravity feed. The flow rates of the three tanks are changes with time, and the flow rate of tank 4 exceeds the flow rate of tank 1 at approximate 9000s. Specially, the tank 2 and tank 5 also begin to offer fuel one after the other with their flow rate increasing and oil level descending. This all characteristics indict that all fuel tanks compete for supplying oil according to its' ability of gravity feed respectively.

As show in Figure 11, the oil pressure in engine inlet decreases gradually. Once the oil pressure less than the minimum pressure limit in engine inlet, the gravity feed oil would not ensure the aircraft fly safely under one flight condition. From Figure 11 we could also approximately predict the maximum flight time under gravity feed.

Conclusion

The thesis established a new calculation model for gravity feed oil of aeropalne fuel transfer system based on flow network theory and time difference method. This model can solve the multiple-branch and transient process of gravity feed oil. The model of non-working pump, check valve and fuel tank are also presented.

The results of the simulation of fuel transfer system for one certain type of aircraft show that all fuel tanks compete for oil supply according to their abilities of gravity feed respectively, but not only one tank offers oil alone.

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