Numerical Study on Cavitation Characteristics of High Speed Fuel Centrifugal Pump

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Abstract: For centrifugal fuel pump operating at high speed, the flow passage components in the pump will be more prone to cavitation, which may lead to efficiency decrease and failure. A single-stage high-speed centrifugal fuel pump is taken as the research object in order to study the phenomenon and the law of cavitation flow in this paper. The influence of different blade inlet angles, rotating speeds and fuel temperatures on cavitation of pump is then studied using numerical method. The results show that properly increasing the blade inlet angle can improve the cavitation performance, and at different rotational speeds, the degree of cavitation is determined not only by NPSHr, but also by Speed C of cavitation, however fuel temperature has rather small influence on the cavitation performance of the fuel pump.

1. Introduction
Centrifugal pump is one of the most widely used fluid machinery[1], it plays an important role in aviation, aerospace, energy, transportation and other industries due to its simple structure, reliable operation, uniform flow and small vibration. With the rapid development of aviation science and technology, the performance of aviation fuel pump has attracted more and more attention. Cavitation has become the main reason for the performance and efficiency decline of centrifugal pump because of its complexity and research difficulty[2], and then cavitation characteristics is of great significance to safe, efficient and stable operation of fuel pump and the performance reliability of aero-engines.

2. Three-dimensional model

2.1. Three-dimensional model
The geometric model of fuel pump is built using three-dimensional modeling software PRO/E and rotary machinery blade design software ANSYS CFX-BladeGen. The main technical parameters are given in Table 1.

| $Q$ (m$^3$·h$^{-1}$) | $H$/m | $n$ (r·min$^{-1}$) | $T$/°C | $\rho$ (kg·m$^{-3}$) |
|-----------------|--------|-----------------|--------|-----------------|
| 55              | 165    | 8500            | 25     | 780             |

The main geometric parameters of the impeller of fuel pump are shown in Table 2. Figure 1 is the three-dimensional geometric models of the impeller, volute and assembly of the fuel pump.
### Table 2 Main geometric parameters of impeller

| Name                      | Calculating Result | Final Results |
|---------------------------|--------------------|---------------|
| Minimum Axle Diameter, $d$ | 15.57 mm           | 16 mm         |
| Impeller inlet diameter, $D_1$ | 56.9 mm         | 57 mm         |
| Impeller outlet diameter, $D_2$ | 126.02 mm      | 126 mm        |
| Impeller Outlet Width, $b_2$ | 7.82 mm           | 8 mm          |
| Blade outlet angle, $\beta_2$ | 29°               | 29°           |
| Blade inlet angle, $\beta_1$ | 26°               | 26°           |
| Blade number, $Z$          | 6.11              | 6             |

#### Figure 1. Geometric model of (a) impeller, (b) volute and (c) assembly of high speed centrifugal fuel pump.

#### 3. Numerical analysis of cavitation

Computational Fluid Dynamics (CFD) and ANSYS CFX were used to simulate the cavitation flow of high-speed centrifugal pump[3]. The cavitation simulation of the fuel pump is carried out for different the blade inlet angle, temperature and rotational speed which have great influence on the cavitation performance of the fuel pump.

#### 3.1. Cavitation at rated operating conditions

Figure 2 and figure 3 shows the variation trend of cavitation shape in impeller blades for different NPSHa(Net Positive Suction Head available) of the fuel pump at the rated working condition (rotation speed is 8500 r/min, flow rate is 5 m$^3$/h and normal temperature is 25 ºC).

#### Figure 2. Cavitation shape of fuel pump blade at the rated working condition with different NPSHa.

#### Figure 3. Vapor volume fraction distribution of central section of the fuel pump impeller at the rated condition with .

It can be found from figure 2 and figure 3 that when NPSHa reduces to 16.76m from 21.6m, a
smaller area of cavitation appears in the blades of the fuel pump inlet, when it continues to drop to 12.19m, the cavitation will fill the entire flow passage of the fuel pump blade, and the pump will gradually begin to fail to work normally. So NPSHA 13.57m will be used for the following study.

3.2. Cavitation at different inlet angles
Figure 4 shows vapor volume fraction distribution at different inlet angles under the same NPSHA(13.57m). It’s obvious that 35° inlet angle is the best. However, the pump efficiency will decrease when the inlet angle is larger than 40°[4], so the latter cannot increase unlimitedly.

3.3. Cavitation at different Speed
In Figure 5, the distribution of vapor volume fraction in impeller section of fuel pump with speed of 7500r/min is smaller than that with speed of 8500r/min and 9500r/min, and the degree of cavitation of fuel pump with speed of 7500r/min is the smallest under the same NPSHa(13.57m). Here, a parameter Speed C of Cavitation is used which is similar to Ns. 

\[
C = \frac{5.62n\sqrt{Q}}{NPSH^{3/2}}
\]  

Speed C of Cavitation can be used to judge the anti-cavitation performance of the device. The larger the C value, the better the anti-cavitation capability of the device.

| n/ (r•min⁻¹) | T/℃ | Q'/ (m³•h⁻¹) | NPSHr/m | C   |
|-------------|-----|-------------|---------|-----|
| 7500        | 25  | 55          | 11.53   | 887 |
| 8500        | 25  | 55          | 12.19   | 905 |
| 9500        | 25  | 55          | 12.75   | 826 |

It can be seen from the table 3 that the fuel pump with the speed of 8500 r/min has the largest C value, while the fuel pump with the speed of 9500 r/min has the smallest C value. It shows that the fuel pump with the speed of 8500 r/min has the best anti-cavitation performance, followed by the fuel pump with the speed of 7500 r/min, and the fuel pump with the speed of 9500 r/min has the worst anti-cavitation performance.
3.3. Cavitation at different temperatures
With increase of the temperature, the density of fuel, saturated vapor pressure and other attributes will be changed, as shown in table 4.

| Table 4. Property parameters of RP-3 fuel[5] at different temperatures |
|--------------------------------------------------|
| T/℃ | ρ/(kg•m⁻³) | μ/μPa·s | Pᵥ/Pa |
|------|-------------|--------|-------|
| 0    | 805         | 1666   | 471   |
| 25   | 780         | 1084   | 1494  |
| 100  | 705         | 423    | 16742 |

Figure 6 shows that the area of cavitation shape in the impeller of the fuel pump at 100℃ is slightly bigger than that at 0℃ and 25℃, which indicates that fuel temperature has weak influence on the cavitation performance of the fuel pump.

Figure 6. Cavitation shape of fuel pump blade at the rated working condition with different fuel temperatures

4. Conclusion
- Properly increasing the blade inlet angle can improve the cavitation performance of the high-speed centrifugal fuel pump. The high-speed centrifugal fuel pump has the best cavitation performance with the blade inlet angle 35°.
- At different rotational speeds, the degree of cavitation can be determined not only by NPSHᵣ, but also by Speed C of Cavitation. The fuel pump has the best cavitation performance under the condition of 8500r/min.
- It can be found that temperature has a weak influence on the anti-cavitation performance of the fuel pump.

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