



RESEARCH ON AIRSPEED CORRECTION TECHNOLOGY OF EJECTION SEAT BASED ON CFD

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Abstract

A certain ejection seat airspeed sensing system is located in the wake flow field of the seat, and the perceived static pressure will produce a large error from the local standard static pressure, requiring aerodynamic corrections to the sensed static pressure to ensure the accuracy of the measured velocity and altitude parameters. In this paper, a technique to correct the static pressure of ejection seats during ejection from the cabin is proposed, which combines CFD simulation and successive iterative approximation algorithm. CFD simulation method was used to simulate the dynamic flow field during the seat egress from cabin, and the total and static pressure data measured by the pitot tube sensing system at ejection velocity below 3 Ma were analyzed. The total and static pressure values at different ejection speeds were calculated with the principle of "total pressure taking the maximum and static pressure taking the minimum", and the relationship curves of the static pressure correction coefficient with ejection velocity were obtained. A successive iterative approximation algorithm was used to correct the measured static pressure based on the relationship between the static pressure correction coefficient and the ejection velocity (Mach number). The calculation results show that the maximum error of perceived total pressure and static pressure simulation values with test values is 2.5% at different speeds, and the maximum error of felt static pressure simulation is 1.9%. The CFD simulation accuracy is high, and the simulation results can be used as input for aerodynamic correction. When the ejection velocity is less than Mach 3, the static pressure correction coefficient decreases monotonically with the ejection velocity increasing, and the successive iterative approximation calculation converges. The maximum error between the static pressure correction value calculated by the successive iterative approximation algorithm and the static pressure at the test site is 3.8%, and the maximum error between the corrected velocity and the true velocity at the test state is 4.1%. The correction errors are all less than 5%, which meet the requirements of ejection seat control program design. The data corrected by this method can be applied to engineering practice, providing a basis for the establishment of ejection seat control program.

Keywords: dynamic CFD, successive iterative approximation, ejection seat, pitot tube, aerodynamic correction

1. Introduction

The ejection seat airspeed sensing system is used to gauge the total pressure and static pressure of the seat during its motion, from which the parameters such as airspeed, barometric pressure, altitude, etc[1]. are deduced, which are important information to ensure the success of ejection lifesaving. The control system chooses to perform the appropriate ejection procedures based on the velocity and height data measured by the pitot system, the precision of which will affect the ejection sequence, directly related to seat performance as well as crew safety survival[2]. Because the airspeed sensing system is located in the wake field of the seat, the complex airflow in the wake field can interfere with the seat static pressure sensing system, resulting in errors between the pressure measurements and the local standard pressure values[3]. The greater the ejection velocity, the greater the error between the static pressure measurements and the standard static

pressure values[4].

This paper combines the CFD method and successive iterative approximation algorithm to correct the perceived static pressure. The aerodynamic corrections are made by successive iterative approximation algorithm based on the total and static parameters obtained from the CFD simulation to improve the accuracy of parachute control and ensure a safe rescue at high altitude.

2. Theoretical basis and correction method

2.1 Aerodynamic correction theory

From aerodynamic theory, the relationship between total pressure P_t , static pressure P_s and Mach number M can be determined by the following calculation formula[5]:

When $M=1$,

$$P_t = P_s \left(1 + \frac{k-1}{2} M^2\right)^{\frac{k}{k-1}} \quad (1)$$

When $M>1$,

$$P_t = \frac{k+1}{2} M^2 P_s \left(\frac{(k+1)^2 M^2}{4kM^2 - 2(k-1)}\right)^{\frac{1}{k-1}} \quad (2)$$

Where k is the adiabatic index, and for air $k=1.4$

2.2 Successive iterative approximation correction method for seat static pressure

Because the static pressure measurement point is at the back of the seat and in the wake of the seat, the measured value of static pressure is smaller than the ambient pressure, and the difference between the two is related to Mach number M . This difference will cause the speed calculated by the total pressure and static pressure sensed by the airspeed sensing system to be different from the real speed. Therefore, it is necessary to correct the static pressure sensed. If the static pressure correction factor is α , the relationship between α and the perceived static pressure P_{s1} , the true static pressure P_{ext} , and Mach number m can be expressed as:

$$\alpha = \frac{P_{s1}}{P_{\infty}} \quad (3)$$

$$\alpha = f(M) \quad (4)$$

There is an interdependence between the measured static pressure P_{s1} and Mach number M , so the real static pressure P_{ext} and Mach number M cannot be obtained directly, so the iterative calculation method is needed. According to this, the revision method is formulated as follows:

- Determine the upper limit $(P_{ext})_{max}$ and lower limit $(P_{ext})_{min}$ for static pressure calculation. And Mach number calculation upper limit M_{max} , lower limit M_{min} ;
- Beginning calculation of Mach number effective values between the upper and lower limits of the Mach number. Take $M_{11}=M_{min}+0.618(M_{max}-M_{min})$ to obtain the Mach number for the first correction. Compute α_1 by function equation (4), and then get $P_{\alpha 1}=P_{s1}/\alpha_1$ from equation (3), and then compute Mach number M_{21} by formula (1) or (2). If $|M_{21}-M_{11}| < \Delta M_{res}$, then take $M_{last}=(M_{11}+M_{21})/2$ as the effective value to calculate the velocity, otherwise continue the calculation between M_1 and M_2 ;
- α_{last} is calculated from M_{last} as a function of equation (4), and from equation (3) the $(P_{ext})_{last}$ is obtained to calculate the static pressure correction, altitude H , and velocity.

2.3 Aerodynamic correction calculation flow based on the CFD method

According to the successive iterative approximation correction method, to complete the correction calculation, we must first obtain the quantitative relationship between the static pressure correction

coefficient α of the programmable controller and Mach number M , that is, the functional formula (4). Due to the limitation of test conditions, it is necessary to carry out CFD simulation calculation on the perceived static pressure under different speeds and different ejection cylinder strokes according to the working principle of airspeed sensing system, so as to obtain the relationship curve between static pressure correction coefficient α and Mach number M based on the simulation data, and finally carry out the static pressure successive iterative approximation correction on this basis. The aerodynamic correction calculation process based on CFD method is as follows (Figure 1):

- Determine the total pressure and static pressure sensing range of the program controller;
- The maximum Mach number is determined according to the total static pressure sensing range;
- Determine the calculation speed step according to the relevant data of similar products in history;
- Establish the CFD simulation model of the aircraft cockpit and seat;
- The total and static pressure data of different ejection speeds were calculated by CFD simulation;
- According to the working principle of the programmable controller, the perceived static pressure value at different Mach numbers is determined, and the static pressure correction coefficient is calculated;
- The relationship between static pressure correction coefficient α and Mach number M was obtained by cubic polynomial fitting;
- A successive iterative approximation method was used to calculate the static pressure correction value in the range of total static pressure sensing of the programmable controller.

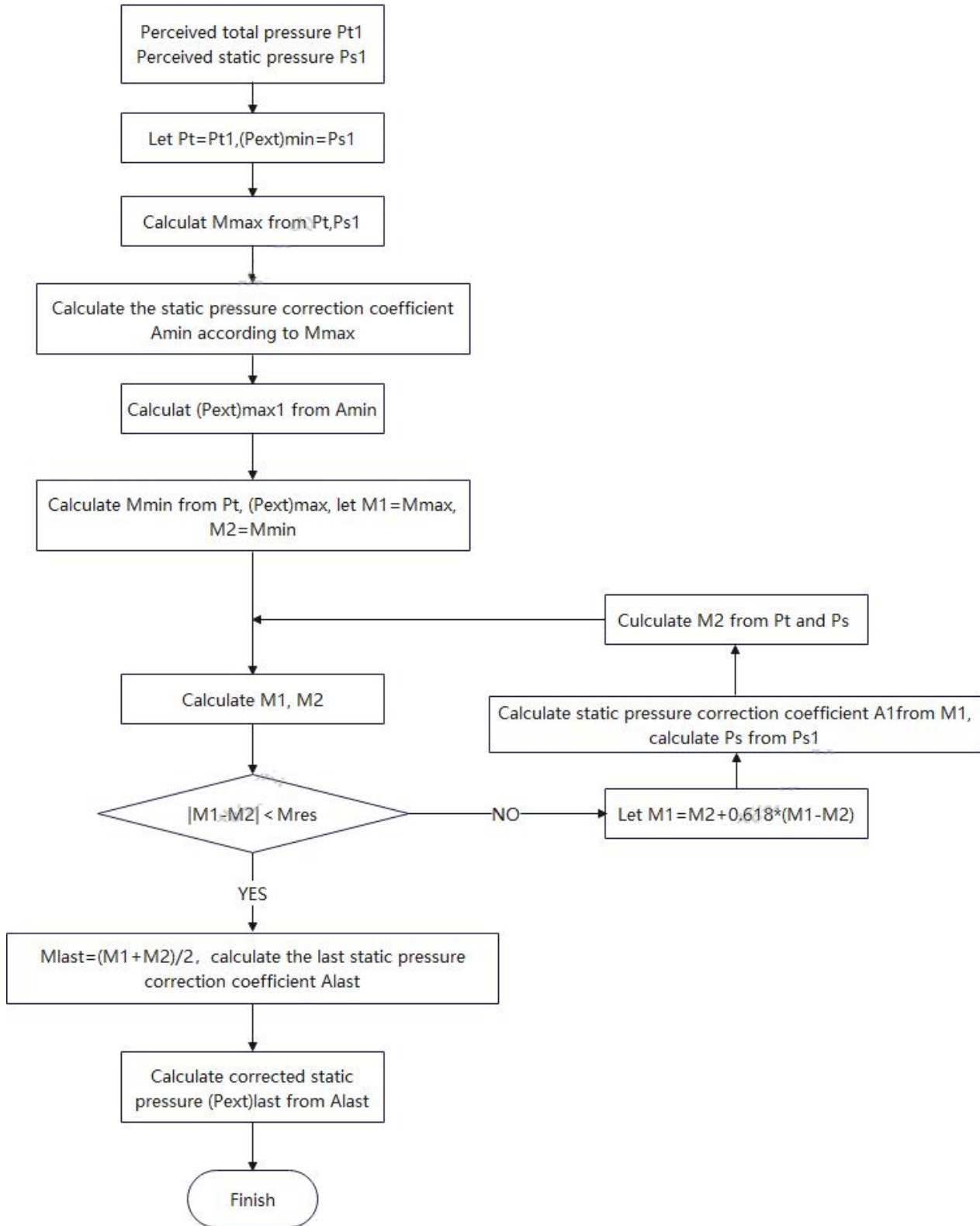


Figure 1 – Correction process flow chart

2.4 Determination of aerodynamic correction state

Considering the range of life-saving envelope and the time delay of direct output and fixed launching of main parachute in the airspace above 7000m, it is preliminarily determined that the total pressure sensing range of the program controller is 40kpa~186kpa and the static pressure sensing range is 20KPa~102kpa. When the total pressure is 186kpa and the static pressure is 20KPa, the maximum Mach number is 2.63m according to formula (2). Therefore, the maximum Mach number of CFD simulation is set as 3, and the environmental parameters of the flow field are sea level atmospheric parameters. The number of CFD simulation states is 104, and the number of

aerodynamic correction States is 6174.

3. Calculations

3.1 Total static pressure simulation results and errors

CFD simulations were performed for three different test velocity regimes, and compared with test data from these three regimes to verify the accuracy of the CFD simulations. Transient calculation and grid updating are used in the calculation process, and the time step was 0.1 ms.

Figure 2 shows the flow field velocity and static pressure cloud charts during ejection from the cabin, Figure 3 and Figure 4 show the total pressure and static pressure simulation value versus time curve during ejection from the cabin, and Table 1 shows the total pressure, static pressure simulation value and error table for comparison with test value. As shown in Figure 2, at the beginning of egress, the pitot tube and seat are below the aircraft windshield, and the surface pressure of the human seat system is less than the ambient pressure. During egress, the seat position rose and began to be blown by airflow, with the pitot tube fully entering the region of high velocity airflow at about 0.08 s, creating a distinct shock wave in front of the pitot tube. The seat back is always in the wake zone, and the pressure in the static pressure acquisition area at the seat back is always less than the ambient pressure. From Figures 3 and 4, the ejection seat felt the total pressure first increased and then decreased due to the effects of the cabin windshield wake flow field, reaching a peak of about 0.08 s after ejection initiation. The greater the ejection velocity, the greater the difference between the maximum felt total pressure and the initial value. Due to the direct effect of the canopy wake field, the process of felt static pressure fluctuation is complex, but always fluctuates in a small range. The maximum error between the total pressure simulation value and the test value in each calculation state is 2.5%, and the maximum error of static pressure simulation is 1.9%.

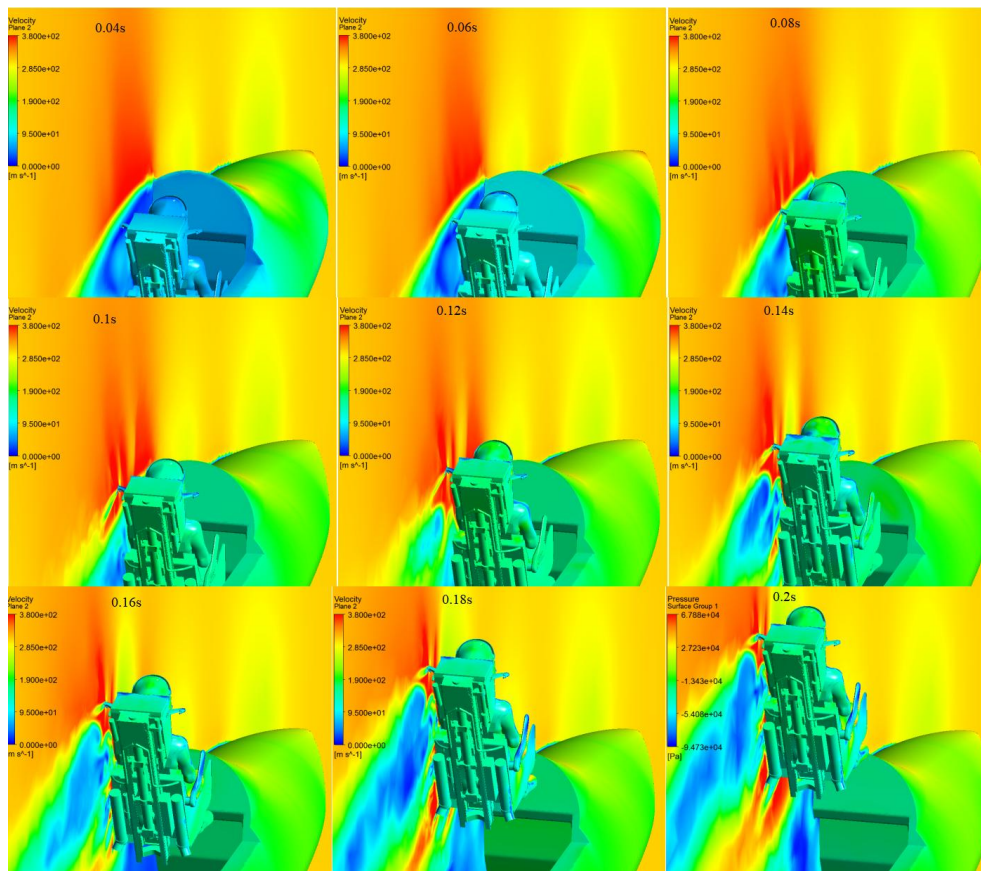


Figure 2 – Section velocity cloud diagram at pitot tube and seat back pressure cloud diagram

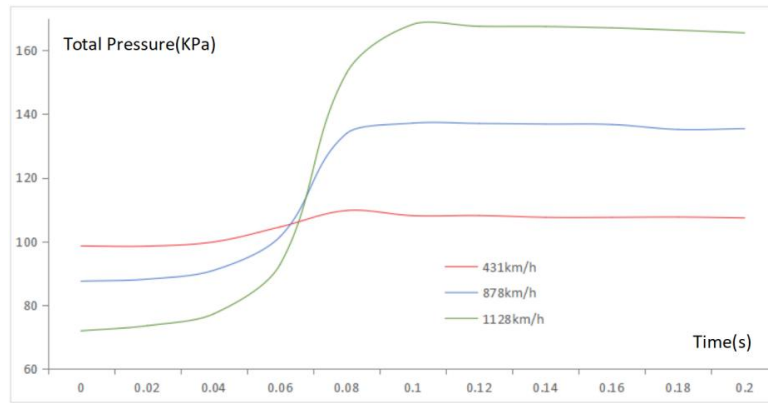


Figure 3 – Total pressure simulation value variation curve during ejection from the cabin

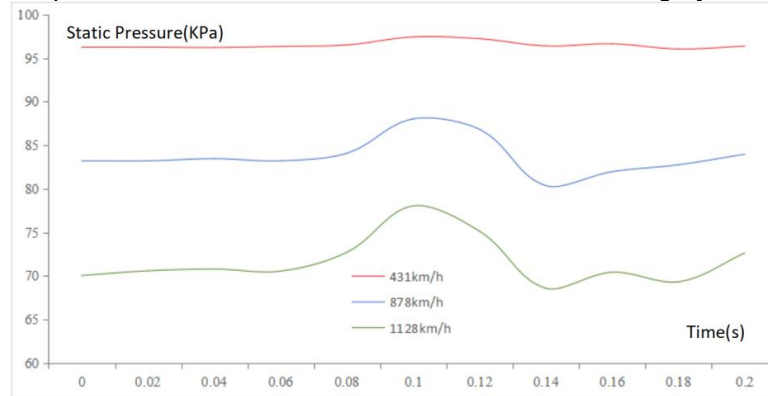


Figure 4 – Static pressure simulation value variation curve during ejection from the cabin

Table 1 – Table of simulated values of felt total pressure, felt static pressure and comparison error with test values

Velocity (km/h)	Simulated static pressure(KPa)	Test static pressure (Kpa)	Simulated total pressure(KPa)	Test total pressure(KPa)	Static pressure error(%)	Total pressure error(%)
431	96.04	94.75	109.66	108.41	1.4	1.2
878	80.36	78.83	141.44	137.94	1.9	2.5
1128	68.57	67.79	173.97	170.04	1.2	1.3

3.2 Simulation results of static pressure correction factor α

During egress, the seat airspeed sensing system follows the principle of "total pressure is taken as maximum and static pressure as minimum", so at the same speed, the airspeed sensing system senses static pressure as the programmed controller senses static pressure at minimum for different egress journeys, and the specific value of the sensed static pressure to ambient pressure is the static pressure correction value. The correction coefficient versus Mach number curve obtained by a cubic polynomial fit is shown in Figure 5, and the static pressure and velocity corrections obtained from the correction coefficient versus Mach number curve correction are shown in Table 2. From Figure 5, the static pressure correction coefficient decreases monotonically with ejection velocity when ejection velocity is less than Mach 3, and the successive iterative approximation correction calculation converges. It is known from Table 2 that the maximum error between the static pressure correction value and the static pressure at the test site is 3.8%, and the maximum error between the corrected speed and the true speed at the test condition is 4.1%. The correction errors are all less than 5%, which meet the requirements of ejection seat control program design. the data corrected by this method can be applied to engineering practice, providing a basis for the establishment of

ejection seat control program.

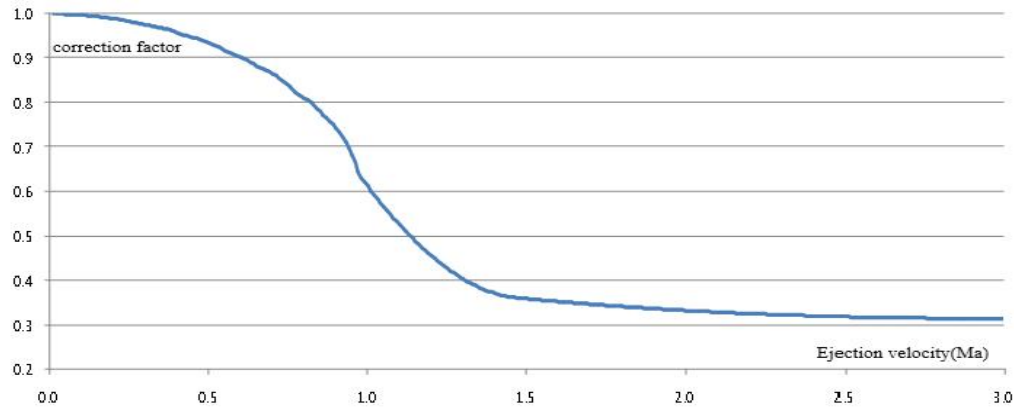


Figure 5 – Seat static pressure correction coefficients vs mach number curve

Table 2 - Static pressure and velocity correction results.

Velocity (km/h)	Corrected static pressure(KPa)	Static pressure at the test site (Kpa)	Corrected velocity(km/h)	Static pressure correction error (%)	Velocity correction error (%)
431	99.15	99.88	441	0.7	2.4
878	96.78	98.62	914	1.9	4.1
1128	95.90	99.74	1150	3.8	2.0

4.3 Static Pressure Correction Calculations

When the correction calculation is made, the different calculation constant A and the convergence coefficient ΔM_{res} are chosen, which will have some effect on the convergence rate and accuracy of the calculation. When $\Delta M_{res} < 0.01$, the calculation results can meet the correction accuracy requirements. For this calculation, the golden section ratio 0.618 is taken as A, and the ΔM_{res} is taken as 0.001. The static pressure correction results within the total static pressure sensing range of the programmer under this set of parameters are shown in Figure 6. The curves from bottom to top are the correction results for a total pressure of 40 KPa to 186 KPa respectively, and the total pressure change step $\Delta P_t = 1$ KPa.

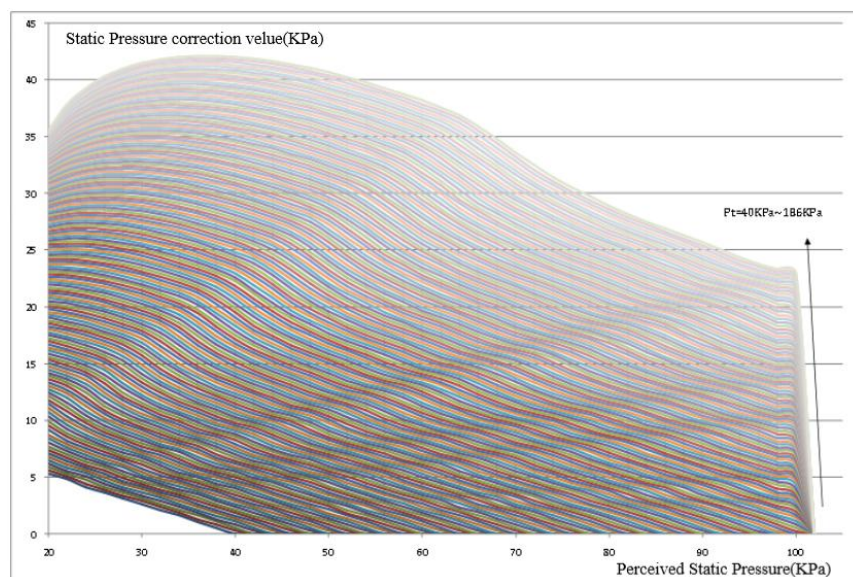


Figure 6 – Figure of static pressure correction results for each computed state

4. Conclusion

- 1) The results of CFD simulation error analysis indicated that the maximum deviation between the simulated total pressure and the test value was 2.5%, and the maximum error between the simulated value of static pressure and the test value was 1.9% at different speeds. The accuracy of CFD simulation could meet the static pressure and speed correction requirements.
- 2) Due to the effects of the cabin windshield wake flow field, the ejection seat felt the total pressure first increased and then decreased, reaching a peak about 0.08 s after ejection initiation. Due to the effect of the ejection seat wake flow field, the process of feeling static pressure fluctuations is complex, but always fluctuates in a small range.
- 3) When the ejection velocity is less than Mach 3, the static pressure correction coefficient decreases monotonically with the ejection velocity increasing, and the successive iterative approximation correction calculation converges.
- 4) The maximum error between static pressure correction value and test site static pressure is 3.8%, and the maximum error between correction velocity and test state true velocity is 4.1%. The correction errors are all less than 5%, which meet the design requirements of ejection seat control program.

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