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Engineering Notes

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Ejection Seat Test Techniques in a High-Speed Wind Tunnel

Chen Dehua* and Wang Jinjun†
Beijing University of Aeronautics and Astronautics, 100083 Beijing, People's Republic of China
and
Wu Wenhua‡ and Chen Liyan§
China Aerodynamic Research and Development Center, 621000 Mianyang, People's Republic of China

Nomenclature

C_A = axial-force coefficient
C_l = rolling-moment coefficient
C_m = pitching moment coefficient
C_N = normal-force coefficient
C_n = yawing-moment coefficient
C_y = side-force coefficient
M, n, L, = pitching moment, yawing moment, and rolling moment
N, A, Y = normal force, axial force, and side force
α = angle of attack, deg
β = angle of sideslip, deg

I. Introduction

MANY fighter planes have crashed in air battles and training. The ejection seat is now the only lifesaving equipment for pilots. According to statistics, about 15,000 pilots have been saved by ejection seats since they were developed. The great improvement of fighters' performance has consequently resulted in more rigorous requirements to the ejection escape system, such as the capability of working at wider ranges of flight attitudes, speeds, and altitudes. Correct prediction of ejection seat performance, based on thorough acquirement of aerodynamic characteristics in a wide range of attitudes, is important in developing new ejection seats because almost all emergency lifesaving happens at aircraft destruction.

Complexities involved in the working conditions, configurations, and mission of the ejection escape system make difficult the theoretical analysis, wind-tunnel testing, engineering estimations, and numerical simulations in predicting and evaluating aerodynamic characteristics, thus excluding full understanding of them. Wind-tunnel tests, rocket-propelled sled tests, and computational fluid dynamics methods are usually used to obtain the aerodynamic characteristics of the ejection escape system. Although rocket-propelled sled tests are conducted at conditions closer to real flight, they are very expensive and the test data are difficult to collect. Compared to rocket-propelled sled tests, advantages exist in wind-tunnel testing such as strict controllability of test conditions, quick and more precise collection of a great deal of test data, etc. However, because of the broad range of α and β ($0 \sim 360$ deg), such tests are more difficult to conduct than conventional wind-tunnel tests. Generally, α coverage of a traditional support mechanism is less than 50 deg, and so it is difficult to use it in wind-tunnel tests with α of $0 \sim 360$ deg. Instead, wind-tunnel tests at different attitudes of pitch and yaw are conducted first, then the data obtained from these attitudes are linked to obtain the overall aerodynamic data. This technique is adopted in the United States, for example. By this method, tests were completed several times with a few models, which took a longer test period, with possible errors in linking the data.

With much attention being paid to the investigation in the United States, a broad and thorough investigation on aerodynamic characteristics of the ejection seat has been carried out, especially at high speeds, for instance, the ejection escape systems on B-47, F-101, F-106, F-4, and other aircraft were investigated in Arnold Engineering Development Center 16-ft wind tunnel (AEDC 16 T) with many specially designed test devices.[1,2]

A new generation of the ejection seat is being developed in the People's Republic of China, which requires thorough research of the aerodynamic characteristics at entire attitude ranges of α ($0 \sim 360$ deg) and β ($0 \sim \pm 180$ deg). Thus, we have developed test techniques for the ejection escape system in 1.2-m high-speed wind tunnel of the China Aerodynamic Research and Development Center (CARDC). The test techniques are introduced, and representative test data are presented in this paper.

II. General Technical Scheme and Its Implementation

A. General Technical Scheme

High-speed ejection seat tests are usually conducted in large wind tunnels ($3 \sim 4.44$ m) with scaled models ($1{:}5 \sim 1{:}1$), to exactly simulate real conditions and to get more practical test data. Because there are no such large high-speed wind tunnels in China, to obtain enough reliable data with acceptable cost, we have developed the test techniques in a 1.2-m high-speed wind tunnel with a set of specially designed test setups that are capable of reaching the entire α range from 0 to 360 deg and β from 0 to 180 deg continuously without changing models and balances.

B. Patented Model Support System

A patented side wall support system with bow rod of right angle (SWSRA), shown in Figs. 1 and 2, is developed for the test, which can vary α continually from 0 to 360 deg and β from 0 to ± 180 deg without changing the models and balances. SWSRA is composed of three main parts. 1) The supporting arm is attached to the side wall rotational window with which β can be varied from 0 to 180 deg when the balance is inserted from the right into the model and from 0 to -180 deg when the balance is inserted from the left. 2) The balance arm lies in the central area of the test section, and with the balance mounted on its left end and a harmonic step motor in its right end, α can be changed from 0 to 360 deg. 3) The connecting arm is used to connect the supporting arm and the balance arm. In addition, an industrial personal computer is used to control the step motor

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*Ph.D. Candidate, Fluid Mechanics Institute.
†Professor, Fluid Mechanics Institute; jjwang@buaa.edu.cn.
‡Senior Engineer, High Speed Institute.
§Engineer, High Speed Institute.

Table 1 Balance design loads for the human seat system

Component	Designed load, N/N · m
N	1300
M	100
A	1900
L	130
Y	1800
n	65

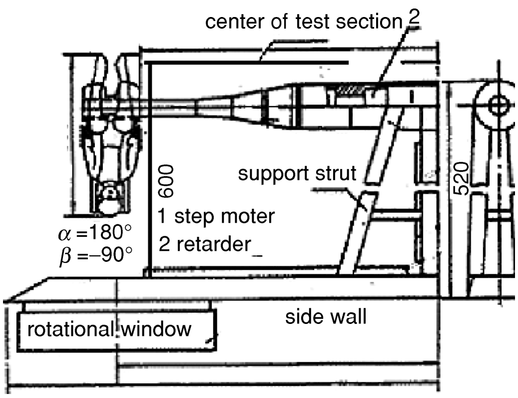

Fig. 1 Structure of patented SWSRA.

Fig. 2 Model installation and position in wind tunnel.

and four thin beams are used to strengthen SWSRA while lessening its blockage. Comprehensive knowledge involving aerodynamics, balance, structure, computer, control, etc., is needed in designing the support system. The support system can not only vary α from 0 to 360 deg and β from 0 to $\pm$180 deg continuously, but also can ensure the model be positioned in the center of revolution of the rotational window and within the uniform flowfield area of the test section.

C. Special Thick and Short Force Balance

The balance is another important device for the test. When used with SWSRA, the balance elements should not be exposed in the flow to ensure its normal performance; thus, the total balance length should not exceed 0.09 m, which is far shorter than traditional lengths. At the same time, because of the large model loads (Table 1), the diameter of the balance should not be smaller than 0.03 m, which results in great difficulties in balance design and manufacture. The balance design loads are shown in Table 1.

Usually, the ratio of length/diameter of a traditional balance is $6 \sim 10$. For the small size of less than 90 mm and the large design loads, it is very difficult to ensure reliable connection between the balance and the model and easy assemblage, and at the same time to provide enough space to hold the elements to meet the test requirements. The balance adopts a three-piece-beam structure arranged symmetrically. Limited by the size, the axial force element X is not designed separately. It is located in the middle of the balance and

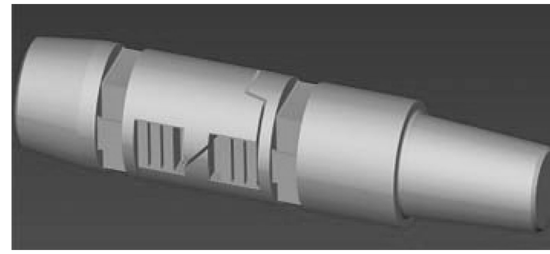

Fig. 3 Special balance.

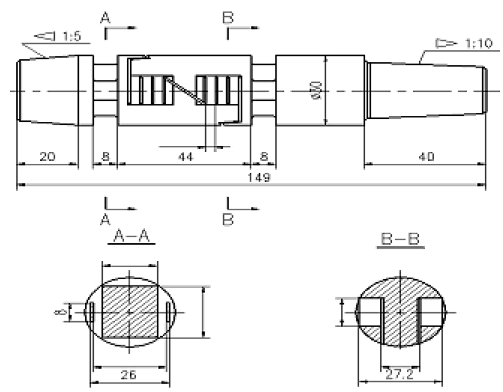

Fig. 4 Main sizes of special balance elements.

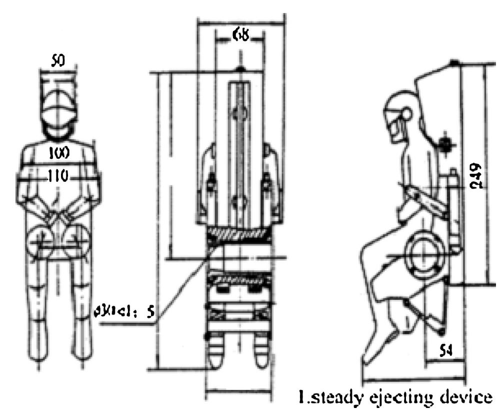

Fig. 5 Ejection seat model.

is measured by the four drag-supporting beams near the element symmetric center. The balance configuration is shown in Fig. 3, and the main dimensions of the special balance elements are shown in Fig. 4. This design not only shortens the total balance length, but also enhances the overall balance stiffness.

To guarantee the reliability and accuracy of the balance, ANSYS software was used to analyze the sensitivity and strength. Both the static calibration and the dynamic calibration meet the requirements.

D. Model

A geometrically similar model was used for this investigation, and it was scaled 1:5 to the real ejection escape system. The maximum blockage ratio of the model in the wind tunnel is only 0.61% ($\alpha = \beta = 0$ deg). The model is 0.338 m long, 0.094 m wide, and 0.146 m thick, details of which are given in Fig 5. Different from traditional model, the force balance is inserted near the pilot model's hip from one side of the model.

E. Wind Tunnel

The test technique for the ejection seat is developed in 1.2-m transonic and supersonic wind tunnel of CARDC, which is a semi-circuit intermittent one. Its layout is shown in Fig. 6. It has two interchangeable test sections, their cross section being 1.2×1.2 m.

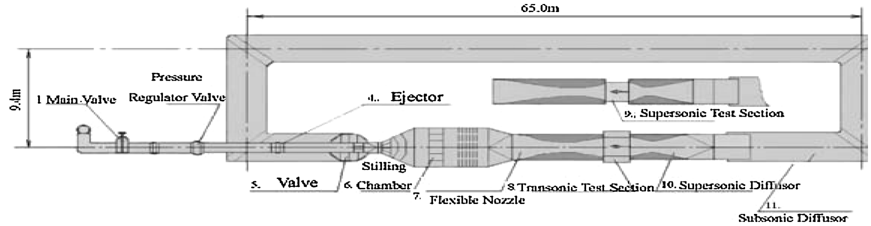

Fig. 6 CARDC 1.2-m wind-tunnel layout.

Fig. 7 Model test conducted on side bent support system when $\alpha = 0$ deg and $\beta = 0$ deg.

The transonic test section is 3.6 m long. The tunnel is equipped with a two-dimensional flexible nozzle for changing Mach number and a movable supersonic diffuser.

F. Test Method

The balance is mounted to the ejection seat model from the right or the left (Fig. 7); therefore, the angle between the support system and the stream is equal to or less than 90 deg which means that the model is always located in the front of the support system in relation to the flow.

The value of β is changed through the side wall rotational window and the value of α by the step motor separately. The tests were conducted either in continuous variation of α step by step (any $\Delta\alpha$) from 0 to 360 deg or 360 to 0 deg at fixed β and Mach number (Fig. 7) and with β changed from 0 to ± 180 deg with any $\Delta\beta$, or in continuous variation of β step by step by the rotational window mechanism from 0 to ± 180 deg at fixed α and Mach number.

Both α and β of the ejection seat model are defined in relation to the stream. Here, the model (pilot) is assumed at $\alpha = 0$ deg and $\beta = 0$ deg when facing forward to the stream.

III. Test Results and Discussion

A. Data Processing and Error

The following corrections were made to the test data: 1) elastic angle effects of the balance and support system on both α and β, 2) noncoincidence effects of the model reference center and the balance calibration center on moments, and 3) effects of model weight on forces and moments.

Repetition test errors in the aerodynamic coefficients were calculated according to the root mean square errors of seven repeated tests at $\alpha = 40$ deg and $\beta = -60$ deg. The results are listed in Table 2.

Table 2 Root mean square errors for aerodynamic coefficients of the model

	σ					
M	σC_N	σC_m	σC_A	σC_l	σC_y	σC_n
0.60	0.00255	0.00552	0.00454	0.000506	0.000107	0.000106
0.90	0.00070	0.00265	0.00188	0.000529	0.000148	0.000621
1.20	0.00102	0.00063	0.00080	0.000265	0.000084	0.000343

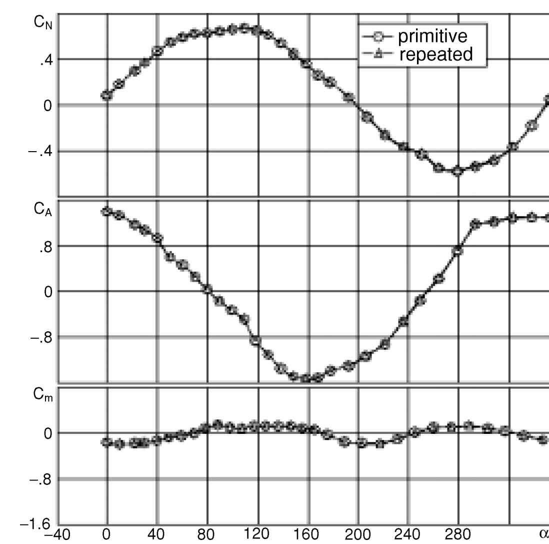

Fig. 8 Force coefficients of two repeated tests when $\alpha = 0$ deg and $\beta = 0$ deg.

B. Reliability Analysis of Test Results

1. Repeatability of Test Results

From the root mean square errors of the seven repeated ejection seat model tests given in Table 2, we can see the test precision is high. Figure 8 shows the results of two repetition tests, and it is easy to see the good repeatability of the aerodynamic coefficients. The coefficients at $\alpha = 0$ and 360 deg are basically the same, and the model attitudes are basically the same, too. These results indicate that the balance and the whole measurement system perform well.

2. Support Interferences

Support interferences can strongly affect data accuracy; sometimes they may reduce the precision of the wind-tunnel test data seriously. Therefore the support interferences of SWSRA must be evaluated. In this paper, the interferences were obtained by comparison tests with and without a dummy strut. In the test, the model was mounted on SWSRA, and at the same time a dummy strut, whose configuration was geometrically the same as the balance, and the real strut were mounted on the top wall to simulate the overall configuration of the balance and the strut, shown in Fig. 9. The aerodynamic interference corrections of the strut to the ejection escape model were obtained by subtracting the results without dummy strut from those with dummy strut at $\alpha = 0 \sim 360$ deg ($\beta = 0$ deg). Figure 9 shows part of the test results.

It can be seen from Fig. 10 that the strut interferences vary reasonably with α and that the test results with and without the dummy

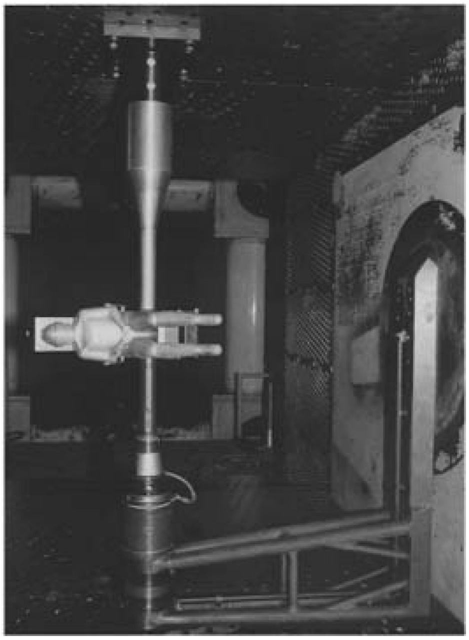

Fig. 9 Support interference test.

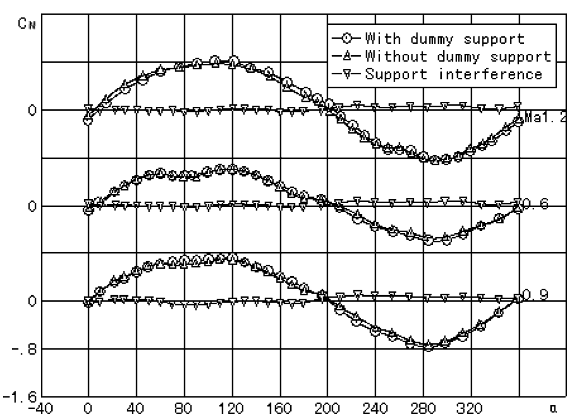

Fig. 10 Comparison between tests with and without dummy support.

strut agree well basically, indicating that support interferences of SWSRA are minor. In conclusion, the support system developed for the test is feasible and reliable.

C. Comparison Between Present and Traditional Test Results

A comparison of the present test results with those obtained in AEDC 16T with an F-106 one-half scaled ejection seat model in Ref. 1 is shown in Fig. 11. Except for an ejection stabilizer installed in the present model, there is little difference between the configurations of the two ejection seats. The test results of the model F-106

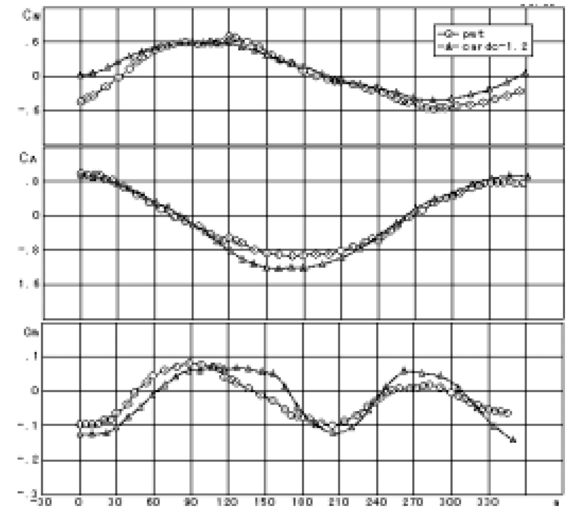

Fig. 11 Test results gained in 1.2-m wind tunnel compared to that in 16-ft. wind tunnel, $M = 0.90$ and $\beta = 0$ deg.

were obtained with a tail support. The range of α of $0 \sim 360$ deg was divided into three parts, namely, $0 \sim 120$ deg, $120 \sim 240$ deg, and $240 \sim 360$ deg, and β is $0 \sim -45$ deg. From Fig. 11, we can find that curves of the present tests vary smoothly with α, but those of AEDC presented discontinuity at the connection points of α. Although the results obtained in the two tunnels show the same variation regularity, they are of different values because their configurations are not the same. This comparison indicates that the test results presented in this paper are reliable.

IV. Conclusions

1) The test results show that the support system is reasonably structured and easy to be operated and that the test results are precise and reliable, indicating that the general technical scheme adopted is feasible and that the test techniques developed in this paper are successful. This is an innovative development in the related test techniques, and this test technique tackles successfully a key problem of conducting the ejection seat tests at high α and high β in 1.2-m high-speed wind tunnel with only one model.

2) This investigation can not only meet the requirements for ejection seat tests at subsonic and transonic speeds and $\alpha = 0 \sim 360$ deg and $\beta = -180 \sim 180$ deg, but also extend applications to the tests at high α of airplanes, missiles, and blunt bodies.

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