Wind Tunnel Test of a Canard Airplane

Chung Jindeog*, **Cho Tahwan**
Senior Engineer, Korea Aerospace Research Institute
Lee Jangyeon, Sung Bongzoo
Principle Engineer, Korea Aerospace Research Institute, Taejon 305-600, Korea

A low speed wind tunnel test was conducted for a canard airplane model in KARI LSWT. The purpose of the presented paper is to investigate the proper testing approach to correct tare precisely and the interference effects for the canard models which has 21% of canard-to-wing area ratio. Most of tests were performed with image system installation for various elevator deflection conditions at the fixed canard incidence angles. To evaluate the effectiveness of the image system, the obtained correction quantity at an zero elevator setting condition with image system was applied to the rest of elevator deflections and compared with the acquired results for all elevator deflections with image system. Test result showed that the amount of correction quantities were strongly dependent on the elevator deflections, and the difference in aerodynamic coefficients for two approaches was gradually amplified as the elevator deflection angles increased. An adoption of the image system was strongly recommended for the higher canard-to-wing area ratio model, if a proper level of accuracy was required.

Key Words: Wind Tunnel Test, Canard Airplane, Image System, and Correction Quantity

1. Introduction

Wind tunnel test of a canard airplane was conducted in KARI LSWT as a part of experimental 4-passenger airplane development plan. To measure the aerodynamic characteristics of forward and straight canards, the incidence angles of canards, deflection angles of elevator, rudder and aileron were changed.

Comparing with a conventional airplane configuration, the canard wake causes flow disturbance on the root section of the wing, and downstream flow pattern of canard induces different flow angularity toward the wing. Those effects due to the presence of canard, especially high canard-to-wing area ratio, do not allow a straight forward approach in the wind tunnel test.

* Corresponding Author,
E-mail: jdchung@kari.re.kr
TEL: +82-42-860-2322; **FAX**: +82-42-860-2604
Senior Engineer, Korea Aerospace Research Institute, Taejon 305-600, Korea. (Manuscript **Received** June 8, 2001; **Revised** October 22, 2001)

To obtain the required level of data accuracy, a very conservative approach in the canard model test was done in KARI LSWT (Cho, T., Chung, J., Sung, B., 2000).

Wind tunnel tests for canard airplane configurations have been continuously performed. Ostowari and Naik (1988) investigated the stability and control characteristics of the model depending upon the size of canard and the distance between canard and main wing. Rom et al. (1989) compared the result of wind tunnel test for delta type canard with CFD calculation. However, those papers did not present what efforts should be devoted to measure precise aerodynamics coefficients by using external and internal balances.

To measure forces and moments exerted on the model itself, the image system is commonly used as a standard method in external balance system (Barlow, Rae and Pope, 1999). However, the major concerns in the use of image system are; how to select proper testing conditions such as specific elevator deflection or all the cases and whether there are enough testing time and budget to accommodate a test.

For a conventional airplane configuration test, the image system was only used for the critical condition such as baseline configuration and employment of high lift devices or the absolute magnitude of drag components required, and most of tests were done by using the previous results for similar airplane configurations. With the lack of database for the canard airplane configuration in KARI LSWT, the image system was applied for all elevator deflection conditions. Even though the adoption of the image system required lots of time and budgetary burdens to change model configuration and extra wind-on time, the application of the image system for the canard model test was the best choice due to the current model geometric characteristics, that had higher canard-to-wing ratio.

The purpose of this paper is to compare the difference in canard airplane aerodynamic coefficients between two approaches. In one approach, we measure the forces and moments using the image system for all elevator deflections. In the other, we measure the correction quantities for a certain elevator deflection, that is elevator 0-degree, and the obtained quantity is applied to the rest of elevator deflections. With these approaches, one can find out what is the proper approach to find a genuine aerodynamic characteristics of having 21% canard-to-wing area ratio.

2. Model Description and Test Conditions

2.1 Model and test facility

A 25% scale model of the canard airplane was used for the wind tunnel test. To measure the aerodynamic characteristics of both the forward and straight canards, the forward canard was installed with 3, 5 and 7 degrees of incidence angles, and the straight canard incidence angles were set at 5 and 7 degrees. The elevator deflections of both canards were -10, -5, 0, 5, 10, 15, 25 degrees, and machined brackets were used to connect canard and elevator. The artificial

Table 1 Model geometric characteristics

Wing Reference Area	0.697 m^2
Canard area	0.147 m^2
Wing MAC	0.345 m
Canard MAC	0.124 m
Length of Model	1.379 m

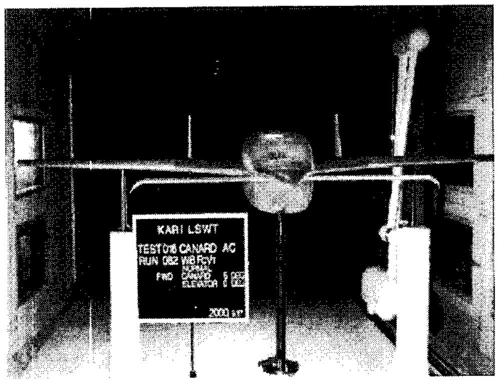

Fig. 1 Model installation in normal configuration

boundary layer transition trip was positioned along the 10% of the main wing mean aerodynamic chord, and the height of trip was 0.35 mm, which was the height of two layer of 3M super33 electrical tape.

Table 1 lists the geometric characteristics of the model. The reference area of both canards was maintained same even though the sweep angles were −10.6 and 0 degrees for the forward-swept and straight canards. The canard-to-wing area ratio was 21%.

The supporting positions of the canard model were slightly different compared with conventional configuration. Pitch-rod, which provided angle-of-attack motion to model, was positioned fore-body of the model as shown in Fig. 1. Bayonets for the wing support were located at 720 mm from body centerline and positioned at 650 mm downstream of the pitch-rod. The inclinometer, which was used to measure the model angle-of-attack, was installed inside of the model spine-block, and the signal-line was routed along the slot of the pitch-rod.

The wind tunnel test was carried out at KARI LSWT. The wind tunnel has a cross-section of 3×4 m and is 10 m long. The general

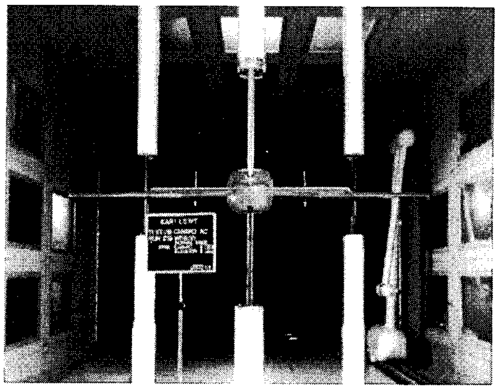

Fig. 2 Normal installation with image system

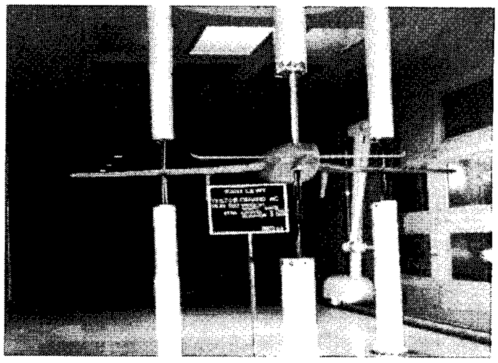

Fig. 3 Inverted installation with image system

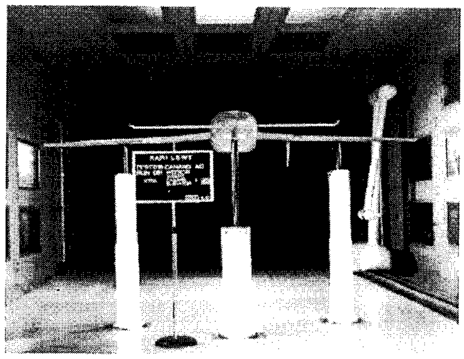

Fig. 4 Inverted installation

characteristics of KARI LSWT including static and dynamic pressure uniformity, axial pressure gradient, turbulence intensity, flow angularity, and boundary layer thickness were discussed by Arnette et al. (2000). The tests were run at the dynamic pressure of 1,500 Pa which corresponded to Reynolds number of 1.2×10^6. Static force and moment data of the model configurations were measured using a pyramidal type external 6-componet strain-gauge balance. The available resolution of balance was 0.02% of full load range. Lift and drag forces, for example, could be precisely measured up to 3.92 N and 1.18 N, respectively. To eliminate thermal hysterisis effects on the balance, the whole balance was enclosed with thermal panel, and temperature and humidity were always kept at constant condition by an A/C unit.

Each pitch sweep was consisted of 19 data points, and the test was conducted over an angle-of-attack range from −4 to 20 degrees. When the model reached canard and wing stall angles, the dynamic pressure gradually lost about 10 Pa. Therefore, the fan RPM changed at least a couple of times to maintain target dynamic pressure as the angle-of-attack of model varied. The average dynamic pressure of the canard test was 1,504 Pa, and standard deviation of dynamic pressure was 4.3 Pa.

As mentioned previously, the main purpose of this paper is to explore the difference in correction quantity and aerodynamic coefficients between the image system correction for all elevator deflections and the reference correction. The installation of the image system was quite essential in the test. Figures 2 and 3 showed normal and inverted model installation with image system. The difference in lift vs. angle-of-attack between two results was used to estimate flow angularity toward model. To eliminate tare and interference effects in the presence of model supports and fairing, the difference between the inverted installation with image system and inverted installation, shown in Fig. 4, was subtracted from the force and moment signal in Fig. 1.

3. Results and Discussion

The effectiveness of the image system to extract precise forces and moments for various elevator deflection was examined by measuring the correction quantities and comparing aerodynamic coefficients. Prior to data comparison, confidence

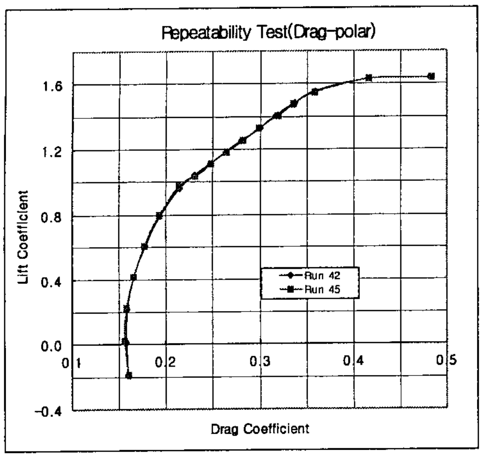

Fig. 5 Drag-polar repeatability

of the measurement will be discussed with repeatability test. The differences in correction quantities between the result of image system for all elevator deflections and the reference correction may give some idea why the image system should be used for the canard airplane test. Finally, the difference in aerodynamic coefficients for both approaches will be presented.

3.1 Repeatability test

The repeatability of the external balance signal and wind tunnel operating condition would have significant meaning since the values to be compared was small. Generally speaking, repeatability and reproducibility check-up during model test were done several times irrespective of model type. The model configuration used for repeatability test was normal configuration with image system, and the forward canard incidence and elevator deflection angles were 5 and 15 degrees, respectively. Figure 5 presents the drag polar repeatability. It shows that the two runs have almost identical drag-polar pattern. The state-of-art 2^{nd} order polynomial curve before canard stall region presents around 3-count difference in minimum drag coefficient at the target lift coefficient.

The repeatability of pitching moment vs. lift coefficient characteristics is shown in Fig. 6. Results display a good agreement at a single glance. To check repeatability more closely, data

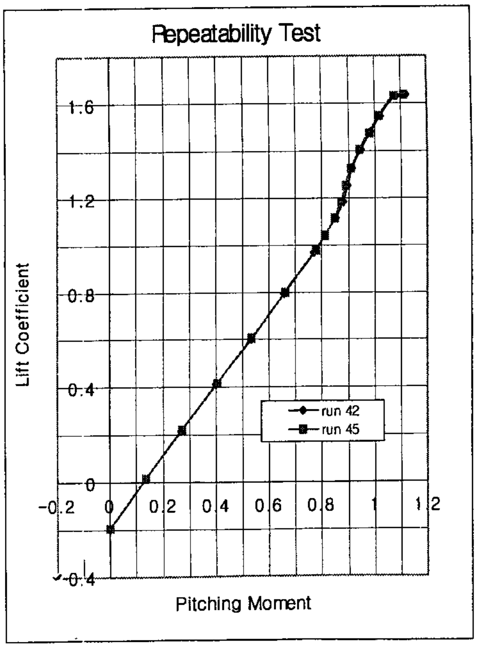

Fig. 6 Lift and P. M. repeatability

are compared at linear region using linear curve fitting. The average difference at linear regions is 0.00063, and it can be negligible. Therefore, one can assume that the data of external balance and tunnel operating conditions provide a reliable level of repeatability during the model test.

3.2 Difference in correction quantities

The correction quantities of the image method for various elevator deflections and reference correction quantity are shown in Figs. 7 and 8. The result was obtained when the straight canard had 3 degree of incidence angle. The solid line in both Figures represents the reference correction, and the rest of symbols show the correction quantities gained with the image system. The difference in correction quantities in Figs. 7 and 8 gradually increased with the elevator deflection angles.

Before canard stall, the difference in correction quantities between the image system and the reference correction was amplified in the order of −5, 5, 15 elevator setting conditions. The positive elevator deflection produced more correction quantity than the negative one. The extra negative

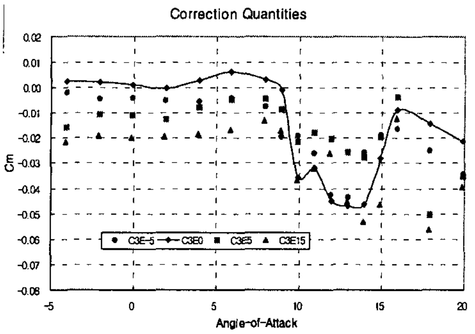

Fig. 7 Pitching moment correction quantities

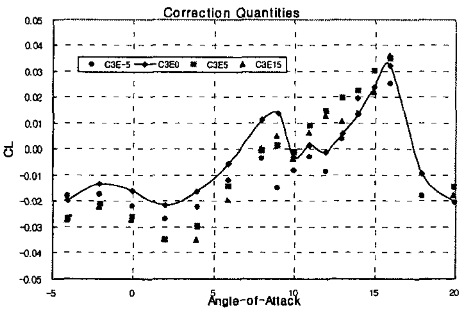

Fig. 8 Lift coefficient correction quantities

pitching moment correction, for example, should be considered at 15-degree elevator condition compared with the reference condition. However, the general patterns were dramatically changed when the angle-of-attack reached over canard stall, and the correction quantities did not show any standard characteristics deflection produced more correction quantity than the negative one.

The lift coefficient correction quantities with angle-of-attack change are presented in Fig. 8. The general behavior of correction quantities was the same pattern as observed in Fig. 7, and that even in reference correction could not be expresed in any form of mathematical formula. Therefore, tare and interference effects should be eliminated by only using the image system approach.

3.3 Discussion

The difference in correction quantities was so far discussed when the canard incidence angle was fixed at 3 degrees. To examine the influence of that correction quantity to the aerodynamic coefficients, the results of the straight and forward -swept canard at 5 degrees of incidence angle

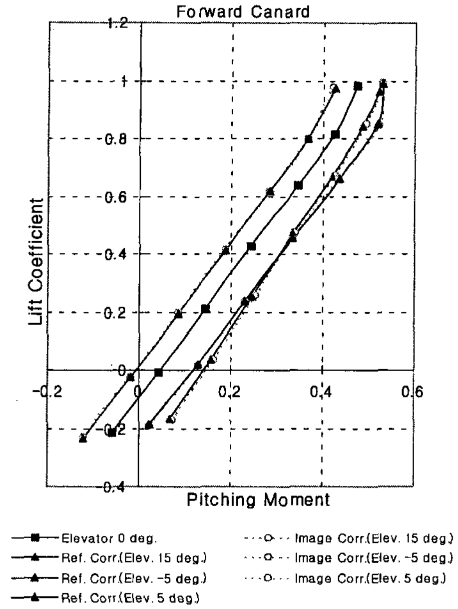

Fig. 9 Forward-swept canard longitudinal stability

were presented.

3.3.1 Longitudinal stability

The pitching moment characteristics of the forward canard are shown in Fig. 9. The distinction between the results of image correction for various elevator settings and the reference correction was not easy. To explore their differences, 1st order curve fittings of lift coefficient and pitching moment were done for linear regions. When the elevator deflection was set at 5 degrees, the difference between the image system and reference correction was an order of thousandths for the given lift coefficient. For the lift coefficient from 0 to 1.0 range, the average pitching moment difference was 0.0011. However, the discrepancies between two approaches were amplified as the elevator deflection angle increased. For elevator 15 degree setting, the averaged difference was 0.012.

Figure 10 shows the straight canard longitudinal stability. The magnitude of pitching moment difference between two approaches for 5 degrees elevator deflection illustrates almost identical level shown as the forward canard. The average difference was 0.0048 after 1st order curve fitting. When the elevator was set at 15 degrees,

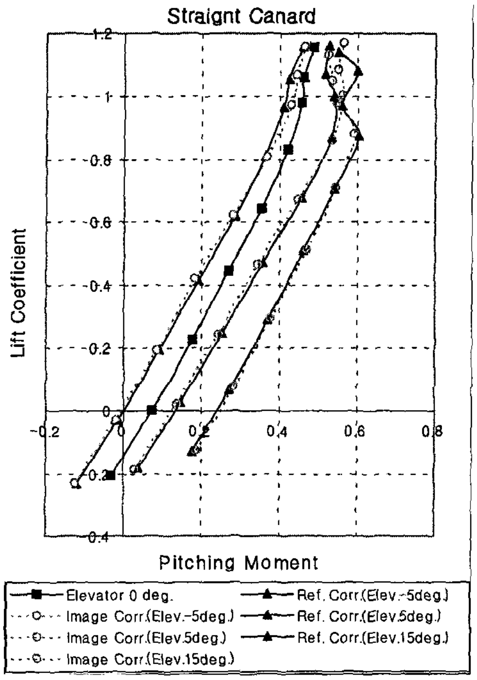

Fig. 10 Straight canard longitudinal stability

the difference was an order of hundredths. The average difference for the straight canard was 0.02, and it was larger than the forward canard case.

The pitching moment difference between two approaches increased as the elevator had higher angle setting, and the reference correction would be ready to suffer loss in accuracy. To obtain precise level of data, adoption of the image system especially at high elevator deflection conditions should be considered carefully.

3.3.2 Drag-polar

Figures 11 and 12 show drag-polar for the forward and straight canards. For the forward canard case, the differences in minimum drag coefficient between adoption of image system and basic approach presented 2 or 3 counts irrespective of elevator deflection conditions. Using the 2^{nd} order of polynomial obtained between lift coefficient 0 to 0.8 region, the average difference between two approaches showed 7 or 8 counts. However, the straight canard displayed somewhat different results. 8 or 10-count difference in minimum drag coefficient existed in the

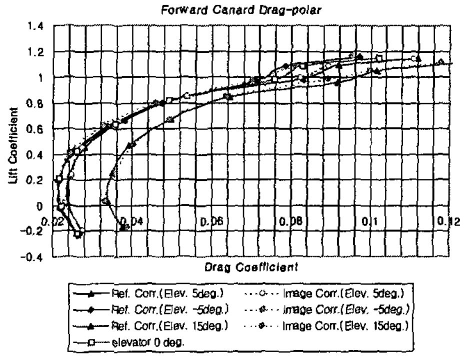

Fig. 11 Drag-polar for forward-swept canard

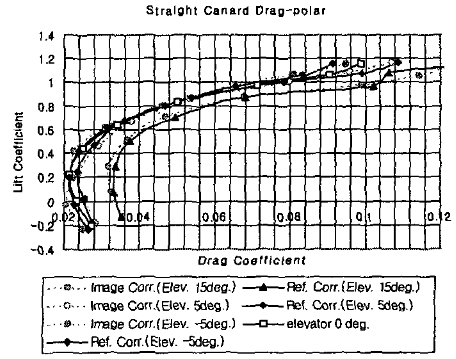

Fig. 12 Drag-polar for straight canard

straight canard case, and those counts were larger than the result of repeatability test. When the elevator was set at -5 and 5-degree deflection, the average difference was 9 counts. But the averaged difference was increased to 13 counts as the elevator deflection increased

From the above results, the sweep angle of canard produced more or less different flow disturbance toward the wing, and it caused the difference in drag-polar. The precise drag-polar could be obtained if one is willing to use the image system.

4. Summary of Results

A low speed wind tunnel test was conducted to determine the effectiveness of adoption of the image system for a model having another lifting surface in front of the wing. The forward-swept and straight canards had 21% of canard-to-wing area ratio and -10.6 and 0 degree sweeps angles, respectively. The results of the tests are summarized as follows.

In the pitching moment and lift coefficient relationship, the difference in aerodynamic coefficients between the use of image system for all elevator deflection conditions and the use of reference correction quantity was amplified as the elevator deflection angle increased. Even the lower elevator setting condition, the pitching moment differences between two approaches was not negligible.

In drag-polar relationship, the difference in minimum drag coefficient was 2 or 3 counts for forward-swept canard and 7 or 8 counts for straight canard. The averaged drag coefficient difference for the straight canard was increased when the elevator was set with higher angle deflections.

To obtain a precise stability and performance characteristics of the canard airplane, the use of image system is highly recommended if the testing time and budgetary issues can be resolved.

Reference

Cho, T., Chung, J. and Sung, B., 2000, "Wind Tunnel Test Canard Airplane," KARI-AD-TM -2000-015.

Ostowari, C. and Naik, D., 1988, "Experimental Study of Three-Lifting-Surface Configuration," *Journal of Aircraft* Vol. 25, No. 2.

Rom, J. Er-El, J., and Gordon, R., 1989, "Measurements of the aerodynamic characteristics of various wing-canard configurations and comparison with NLVLM results," 7^{th} AIAA Applied Aerodynamics Conference July 31-Aug. 2.

Barlow, J. B. Rae, W. H., Jr. and Pope, A., 1999, "Low-Speed Wind Tunnel Testing," 3^{rd} edition, John Wiley & Sons.

Arnette, S. A., Porter, C. B., Meredith, W. S., Hoffman, J. M. and Sung, B. Z., 2000, "Aerodynamic Commissioning Results for the Korea Aerospace Research Institute Low Speed Wind Tunnel," AIAA-2000-0291, 38^{TH} Aerospace Sciences Meeting & Exhibit, Reno, NV.