Wind Tunnel Test of the Straight and Forward Swept Canards

Jindeog Chung*, Bongzoo Sung, Jangyeon Lee** and EungTai Kim****
Aerodynamics Department
Korea Aerospace Research Institute, Taejeon City, Korea 305-333

Abstract

A low speed wind tunnel test for the canard airplane model was conducted in KARI LSWT. To measure the required level of accuracy, the image system was applied for all elevator deflection and different canard incidence conditions. By doing so, the difference in aerodynamic characteristics between the forward swept and straight canards can be precisely evaluated, and the pros and cons of both canards arrangements can be discussed. Compared with both canard configurations at the same incidence angle setting, the straight canard has benefits in lift and drag, and the slope of pitching moment increases more moderately than the forward swept canard. The listed data and discussion would be useful to whom wants to design a canard airplane.

Key Word : straight canard, forward swept canard, drag-polar, canard airplane, image method,

Introduction

The benefits of the additional lifting surface in front of main wing configuration are numerous. The utilization of the canard became a fashion and some of recently developed military airplanes and general aviation airplanes had partially moving or all moving canard. Also the revolutionary concept of UAV especially CRW(Canard Rotor/Wing) has a canard, which uses to generate extra lifting force during transition period. For designing an airplane having canard configuration one must thoroughly understand the effectiveness of the selected canard type.

Compared with the conventional configuration of airplane, the canard airplane relieves the air-load applied on the wing itself which in turn reduces wing structural weight. And the upload from the canard can reduce work-load of the horizontal tail that uses trim airplane movements. Thus, the application of the canard will be affordable means to increase the effectiveness of airplane operation.

Wind tunnel tests for canard airplane configurations have been continuously performed in these days. Ostowari and Naik [1] showed 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. [2] compared with result of wind tunnel test for delta type canard and CFD calculation. The canard wakes causes flow disturbance from the root to middle span sections of main wings depending on the canard size, and the flow angularities toward wing are different due to induced flow pattern of canard. Those effects due to the presence of canard, especially high canard-to-wing area ratio, do not allow a straight forward approach in the

* Principal Researcher
E-mail : jdchung@kari.re.kr, TEL : 042-860-2322, FAX : 042-860-2604
** Senior Researcher

wind tunnel testing procedure. To obtain the required level of data accuracy, a very conservative approach during the canard model test was done in KARI LSWT[3,4,5]. For the model testing periods, the image system was applied for all elevator deflection and different canard incidence setting 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 regarded as the best choice due to the current model geometric characteristics, that was higher canard-to-wing ratio.

In this paper the aerodynamic characteristics of the forward and straight canards are reviewed based on the previously measured data, and the pros and cons of both canard arrangements are discussed to provide some guidelines to whom desires design new airplane configuration with canard.

Model Description and Test Conditions

1. Model Description and Test Conditions

A 25% scale model of the canard airplane was used for the wind tunnel test. To measure the aerodynamic characteristics both of the forward swept and straight canards, the forward swept canard was installed with 3 and 5 deg. of incidence angles, and the straight canard incidence angles were set 3, 5 and 7 deg.. The elevator deflection conditions of both canards were -5, 0, 5, 10, 15, and an extra 25 deg. elevator deflection condition was selected when both canards incidence angle were set at 5 deg.. The connections between canard and elevator were done by using machined brackets. The artificial 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. Transition dots on canard, horizontal and vertical tails were also located along 15%, 10% and 10% of their mean aerodynamic chords respectively.

Table 1 lists the geometric characteristics of the testing model. The reference area of both canards was maintained same even though the sweep angles of the forward swept and straight canards, shown in Fig. 1, were different; forward swept canard was -10.6 deg. and straight one was 0 deg.. The canard-to-wing area ratio was 21%.

Table 1. Model Geometric Characteristics

Wing Reference Area	0.697 m^2	Wing MAC	0.345 m
Canard Area	0.147 m^2	Canard MAC	0.124 m

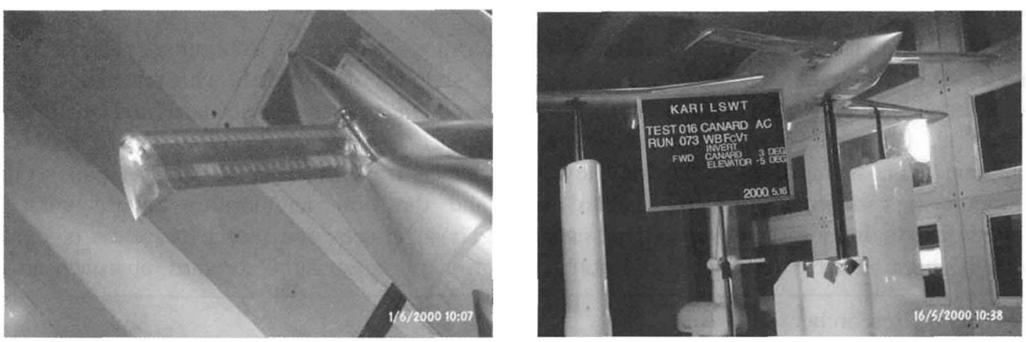

Fig. 1. Straight(left) and Forward Swept Canards

Fig. 2. Canard model in Test Section

The supporting positions of canard model were slightly different comparing with conventional configuration. Pitch-rod, which provided angle-of-attack motion to model, was positioned fore-body of model as shown in Fig.2. Bayonets for the wing support were located 720 mm from body centerline and positioned 650 mm downstream of the pitch-rod. The inclinometer, which was used to measure model angle-of-attack, was installed inside of model spine-block, and the signal-line was routed along the slot of the pitch-rod.

The canard model shown in Fig.2 was tested at 50m/s, and the corresponding target dynamic pressure was 1500 Pa. 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 1504 Pa, and standard deviation of dynamic pressure was 4.3 Pa. The drag-polar was consisted of 19 data points, and the test was conducted over an angle-of-attack range from 4 to 20 deg..

2. Wind Tunnel Facility and External Balance

The wind tunnel test section is 3 x 4 m and 10 m long. The general 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 [6]. The tests were run at dynamic pressure of 1,500 Pa which corresponds to Reynolds number 1.2 x 10^6. Static force and moment data of the model configurations were measured using a pyramidal type external 6-component strain-gauge balance. The available resolution of balance is 0.02% of full load range. Lift and drag forces, for example, can be precisely measured up to 3.92 N and 1.18 N, respectively. To eliminate thermal hysterisis effects on the balance, the whole balance is enclosed with thermal panel, and temperature and humidity are always kept at constant condition by an A/C unit.

Results and Discussion

To evaluate the aerodynamic characteristics of the forward swept and straight canards, the selected test conditions are reviewed. First of all, the general characteristics of the forward swept canard such as lift and pitching moment with angle-of-attack, lift vs pitching moment, drag-polar are shown. And comparison between forward and straight canards is done to illustrate the difference.

1. Forward Swept Canard

The incidence angles of the forward swept canard were set 3 and 5 deg. The lift coefficient characteristic with angle-of-attack is shown in Fig.3. When the forward swept canard is installed with 3 deg. of incidence angle and 5 deg. of elevator deflection angles, it is denoted as Inc(3) & Ele(5) throughout the figures. Enhancement of lift coefficient due to camber effect can be seen as the incidence angle and elevator deflection angles increased.

Slopes of the lift coefficient within linear regions have unique patterns depending on the elevator deflections and canard incidence angles. When the elevator set angles are between -5 and 5 deg., the slopes are gradually increased. However, the deflection angle of the elevator reaches 15 deg., the slope is strongly affected by the canard incidence angle and stall characteristics. Lift curve for elevator 0 and 5 deg. settings can not observe canard stall in Fig.3. However lift coefficient variations due to canard stall are obvious as the elevator setting angles are increased. When the elevator sets 15 deg. and more, the general pattern of lift curve is suddenly changed which in turn cause variation of lift slope. That is, the forward swept canard with elevator 15 deg. at 3 deg. incidence set shows relatively higher values of lift force than the 5 deg. incidence set.

In the level flight condition, the proper angle-of-attack setting can be found by observing the Fig. 4. Most of the canard incidence angles and elevator deflection angles cause pitch-up pitching moment except elevator deflection is set -5 deg. in 3 degree of incidence angle. Since the presence of another lifting surface front of the wing produces additional lift, the aerodynamic center of airplane is positioned front of wing reference point which in turn the pitching moment of the canard airplane has nose-up characteristics.

The longitudinal characteristics of the forward swept canard are shown in Fig. 5. The pitching moment variation with lift coefficient shows kind of gradual increase in the low lift region along with elevator deflections. However the pitching moment patterns are strongly affected by the canard stall behavior as the elevator deflection conditions become higher such as 15 and 25 deg.. The pitching moment after the canard stall can be easily differentiated based on the incidence angle settings; 3 and 5 deg.. When the incidence angle was set 3 deg., the pitching moment did not show any sudden changes. For the 5 deg. incidence cases, the pitching moment did not increase in certain lift

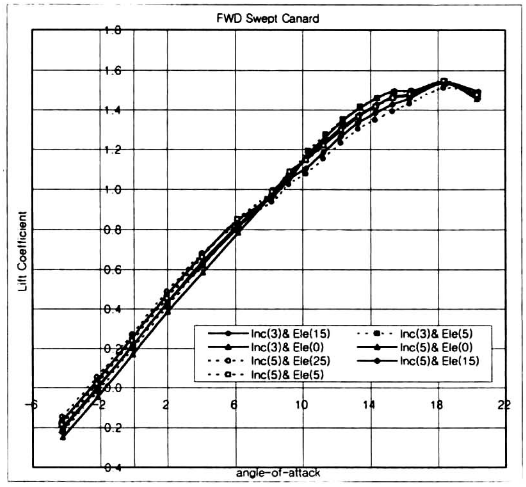

Fig. 3. Forward Swept Canard Lift Curve

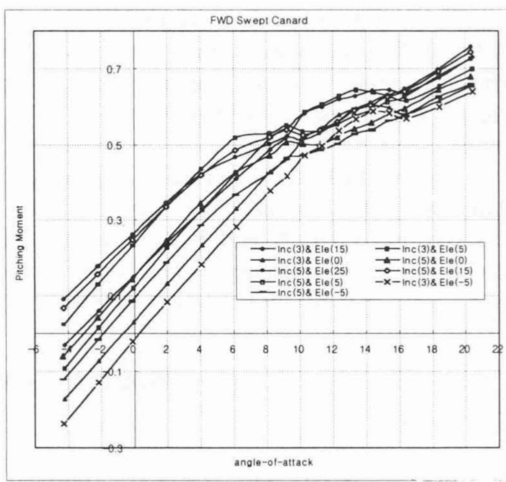

Fig. 4. Forward Swept Canard Pitching Moment

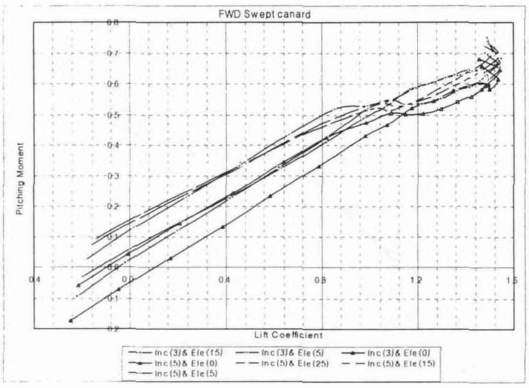

Fig. 5. Forward Swept Canard Lift Coefficient vs. Pitching Moment

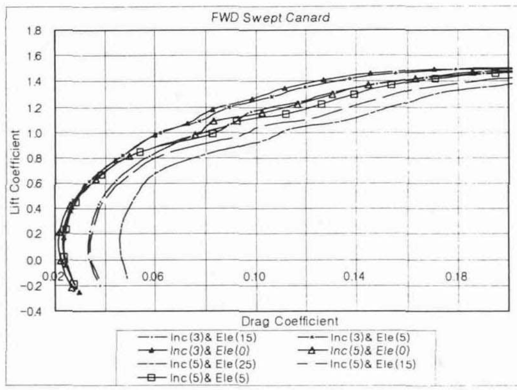

Fig. 6. Forward Swept Canard Drag-polar

coefficient regions and steadily increased again until it reached the wing stall. The general behavior of pitching moment after the wing stall show identical pattern.

Fig. 6 shows drag-polar for the forward swept canard with different incidence angle sets and elevator deflections. It is 5 deg. of incidence angle with elevator deflection 0 deg. that illustrates the minimum drag coefficient. The drag for the 5 deg. incidence setting however increases more rapidly than the 3 deg. condition as the lift coefficient increases. Drag-polar shapes for elevator 0 and 5 deg. in 3 deg. incidence setting seem to be identical for low lift coefficient region. However, the drag coefficient is suddenly enhanced as the 5 deg. of elevator set experienced flow separation.

2. Comparison between Straight and Forward Swept Canards

The aerodynamic characteristics of the forward swept and straight canards are hereby compared with a fixed elevator setting conditions at the same incidence angle. By doing so, the effectiveness of both canards can be easily differentiated. The notations shown Fig. 7 through 10 represent the canard incidence angle and elevator deflection in the following manners; when the forward swept canard having 5 deg. incidence angle and 15 deg. elevator deflection is noted as F5&E15, the same rule is applied for the straight canard.

The straight canard produces more lift force than the forward canard irrespective of elevator deflections. And the differences between two canards at the same elevator deflection are enhanced as the elevator deflection angles increase. The tip section of the forward swept canard will experience faster flow structure break-down than the straight one, and this leads to the reduction of the lift force as shown in Fig. 7. When the elevator was set at 15 deg. separation on the both canards is obvious at 6 deg. angle-of-attack, and the reduction quantity of the lift force seems to be the same order.

The pitching moment variation with model angle-of-attack is illustrated in Fig. 8. The pitching moment shows kind of step enhancement as the elevator deflection angles increase. The forward swept canard however does not follow the straight canard pattern; 15 deg. of elevator deflection produces less pitching moment than the 5 deg. elevator deflection. This is due to earlier flow separation on the elevator surface and in turn generates more strong flow disturbance toward the main wing.

In the linear pitching moment regions, the straight canard has dominance in pitching moment compared with the forward swept one irrespective of the incidence angle and elevator deflections. Around the canard stall regions, the straight canard produces more severe pitching moment variations than the forward one. The straight canard produces more pitching moment than the straight one after the canard stall.

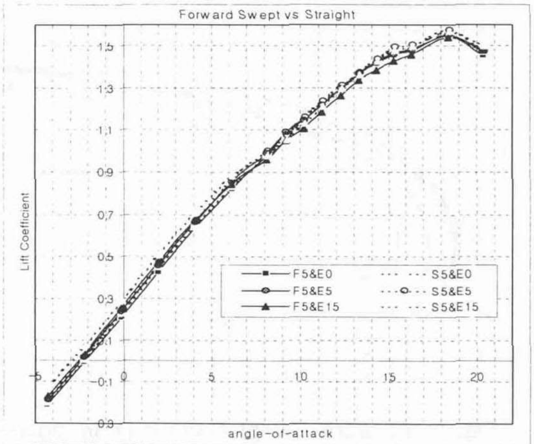

Fig. 7. Lift of the Forward Swept and Straight Canards

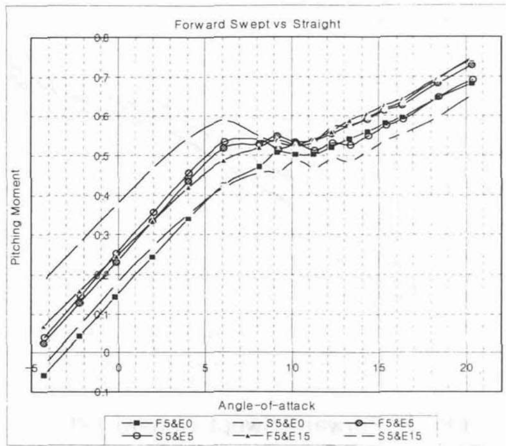

Fig. 8. Pitching Moment of the Forward and Straight Canards

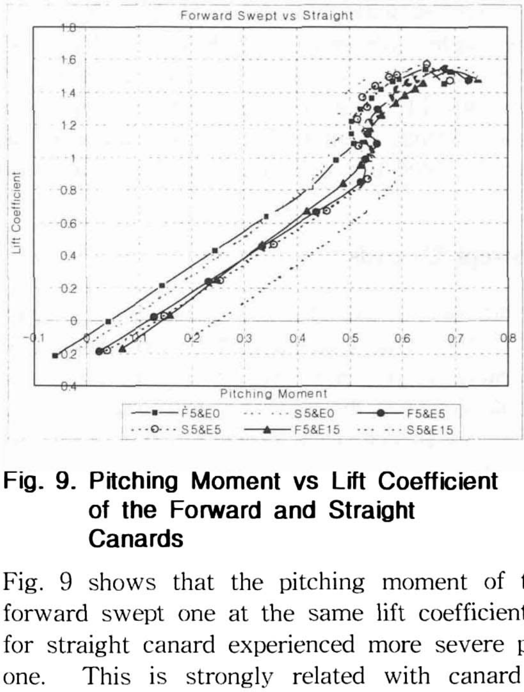

Fig. 9. Pitching Moment vs Lift Coefficient of the Forward and Straight Canards

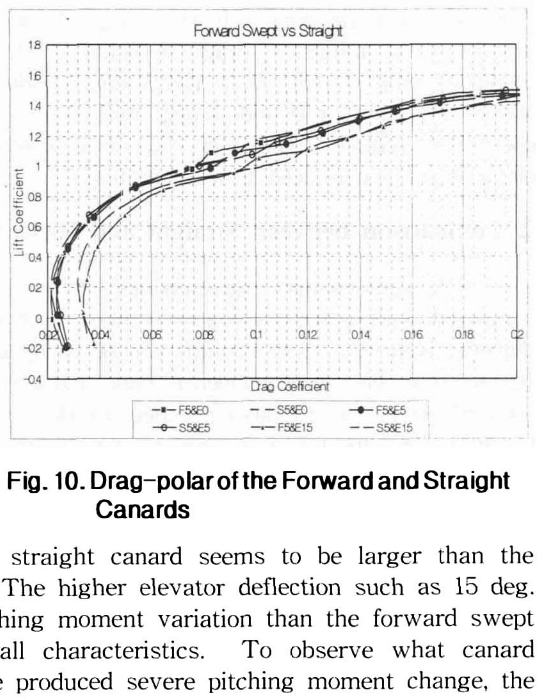

Fig. 10. Drag-polar of the Forward and Straight Canards

Fig. 9 shows that the pitching moment of the straight canard seems to be larger than the forward swept one at the same lift coefficient. The higher elevator deflection such as 15 deg. for straight canard experienced more severe pitching moment variation than the forward swept one. This is strongly related with canard stall characteristics. To observe what canard incidence and what elevator deflection angles are produced severe pitching moment change, the rest of measurement data are reviewed. Compared with the straight canard at 3 deg. incidence, the forward swept one does not show any stiff pitching moment change irrespective of elevator deflection angles even though the results are not shown in the paper. From the above results one can say that forward swept canard with the lower incidence setting may be favorable to avoid sudden pitching moment changes after the canard stall.

Slope that is pitching moment variation with lift coefficient, for the low elevator deflections from 0 deg. to 5 deg. shows that the straight canard has a little bit higher value. However, the straight canard has stiffer slope than the forward one as the elevator deflection condition changed to 15 deg.

Fig. 10 shows the drag-polar for the identical canard incidence setting with different elevator deflections. The minimum drag of the straight canard at 0 deg. elevator deflection is slightly less than the forward one, and the straight canard seems to have less drag coefficient before the canard stall. In the canard airplane cruise regions, the straight canard generates less drag than the forward swept canard.

Conclusions

The general aerodynamic characteristics between the forward swept canard and straight canard are reviewed, and the image system approach to correct flow angularity and interference tare is employed for all canard incidences and elevator deflection conditions.

The straight canard produces more lift force than the forward swept one at the same incidence and elevator deflection conditions. The enhancement of lift force is effective prior to the canard stall angle-of-attack. And the lift force after the canard stalls is suddenly decreased as the incidence angle and elevator deflection angles are increased. In the linear pitching moment regions, the straight canard has dominance in pitching moment compared with the forward swept one irrespective of the incidence angle and elevator deflections. However, the straight canard experiences more severe variations of the pitching moment after the canard stall. The drag characteristics of the straight canard in the cruise conditions have more favorable benefits.

Acknowledgements

The authors gratefully acknowledge the support of the Ministry of Science and Technology through National Research Laboratory Program.

Reference

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

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

3. J. Chung, T. Cho, J. Lee, B. Sung," Wind Tunnel Test of a Canard Airplane", KSME International Journal, Vol. 16, No.1, pp125-131, 2002

4. B. Sung, et al,"Wind Tunnel Test of Canard Airplane", KARI-AD-TM-2000-12, 2000

5. J. Chung,"KARI LSWT Operational Results (The 2nd Wind Tunnel Test of a Canard Airplane)", KARI-AD-TM-2000-015, 2000

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