Wind Tunnel Test of MRP Model using External Balance

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Abstract

A comparative wind tunnel testing of an airplane model was performed at the Korea Aerospace Research Institute Low Speed Wind tunnel(KARI LSWT). The model used for the comparative test was a seaplane model from the Glenn L. Martin Wind(GLM) Tunnel of University of Maryland, U.S.A. The 6-component external balance used in force and moment measurement is pyramidal type, which is a precision device that has strain gauge-type load cell inside of balance and the virtual center of the balance coincides with the tunnel centerline. Image method is adopted to eliminate the tare and interference of the model support, and to correct the flow angularity to the model also. Test results from KARI LSWT were compared with the results from GLM tunnel.

Key Word : Wind Tunnel, External Balance, Image Method

Introduction

Force and moment measurement test by using a standard model is a final step in tunnel performance tests. This paper reports such a test done in the KARI LSWT. The standard model used in KARI LSWT was MRP seaplane owned by GLM tunnel of University of Maryland. Various wind tunnel tests were performed at GLM tunnel such as adding components of the model and deflections of control surfaces[1]. Identical wind tunnel tests were performed at KARI LSWT to check the consistency and accuracy of data in both facilities. The cross-sectional area of GLM tunnel is 66% of KARI LSWT(3 x 4 m), and the maximum speed of GLM tunnel is slightly smaller. GLM tunnel has yoke type external balance. Therefore, the forces and moments are obtained through complicated calculation. The image method were used at GLM tunnel to compensate for the tare and interference effects on model introduced by the model supports and its fairings. General specifications of GLM tunnel are summarized in Table 1.

Table 1 GLM Wind Tunnel facility[2]

Test section size	2.36 x 3.36 (m)
Velocity range	0.9 ~ 103 m/s
Turbulence Intensity	0.21%
Balance type	External Yoke

KARI External Balance

Fig.1 shows model support struts and fairings, strut interface platform, model platform interface which connects balance and strut interface platform of the typical model installation.

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EBMS(Extenal Balance Model Support)

The initial design condition of the EBMS is a severe one. If a model is subjected to the loads shown in Table 2, the deflections of model supports were required to satisfy the following conditions.

- rotation around vertical axis: ± 0.3 deg.
- displacement in axial/vertical directions: ±2mm

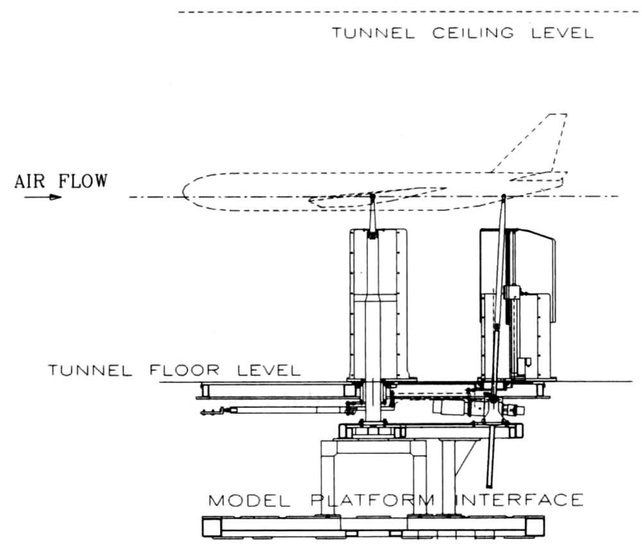

Fig. 1. Model Installation on External Balance

When the supplier designed the model supports and fairing based upon the above conditions, the sizes of strut and fairing were very large and blockage ratio(fairing frontal area/cross sectional area of test section) was about 6%. Since the major factor which increased tunnel blockage ratio was ±2mm displacement design condition, KARI modified the design condition for EBMS. Final design results were that the maximum diameter of the strut was 120mm and maximum thickness of the fairing(RAE 103 airfoil) was 150mm. The blockage ratio of the EBMS in tri-pod configuration, two front struts and a pitch strut at rear, was 3.2 % of the test section.

Pitch fairings, which cover pitch strut were made of one fixed fairing and one elevating fairing synchronized with pitching mechanism. Thus the uncovered length of the pitch strut between model and fairing maintained the initial length regardless of angle of attack change. Fairings were connected with pantograph system which aligns fairing direction to the oncoming flow in yaw motion.

Table 2 Design Load ranges of EBMS

	Tri-pod	Uni-pod
Lift	20,000 N	10,000 N
Drag	6,000 N	3,000 N
Side Force	20,000 N	3,000 N
Pitching Moment	9,000 N · m	2,000 N · m
Yawing Moment	9,000 N · m	2,000 N · m
Rolling Moment	9,000 N · m	1,000 N · m

Strut Interface Platform

Strut interface platform is used to position front and pitch struts and can be rotated 90, 180, and 270 degrees. Fig. 2 shows a general arrangement for tri-pod configuration; front strut can be located ±240, ±480, ±720, ±960mm in side direction from the balance virtual center, and pitch-strut can be placed 350, 500, 650, 800, 950mm downstream from the balance virtual center.

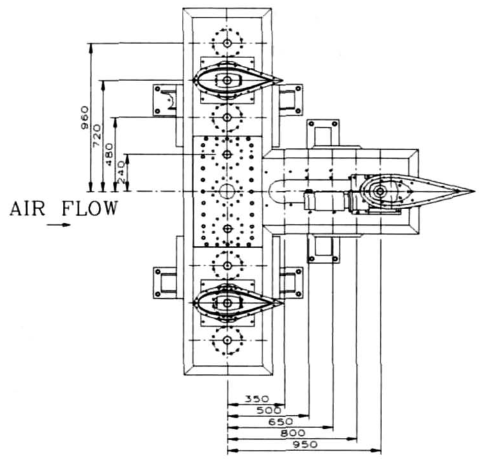

Fig. 2. strut interface platform

External Balance

The external balance in KARI LSWT is virtual center type, which is sometimes also described as Pyramidal type. It means that the virtual center about which the moments are resolved is some way above balance mechanism and the location of the model can be arranged to coincide with the virtual center.

The balance can be elevated to several different heights to suit different model configurations. The virtual center of balance coincides with tunnel center for full span aircraft model test, so called P4. The next virtual center is lowered 750mm from P4 and is used for high speed vehicle test. The virtual center for half-span model test is located at the tunnel floor(1500mm down from P4). Fig 3 shows the balance position at P4.

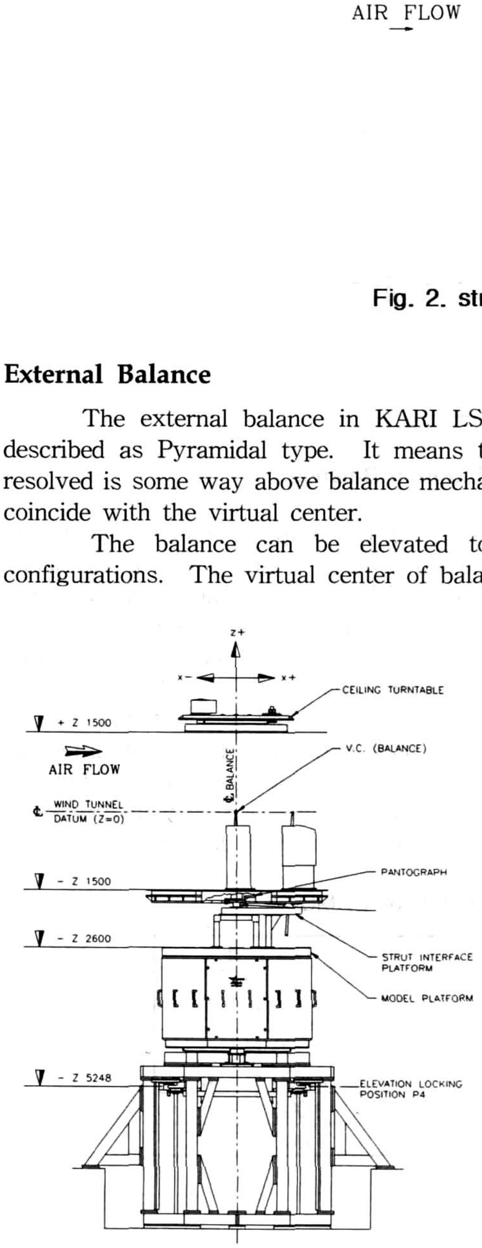

Fig. 3. External Balance at P4 position

The available resolution of six components balance is 0.02% of full load range. Lift and drag forces, for example, can be precisely measured up to 400g and 120g, respectively. To maintain the accuracy of the balance, the whole balance is kept at constant temperature and humidity condition by the air conditioning unit.

SPLAT(Single Point Load Application Test) is used to confirm the repeatability of the calibrated loads previously defined at full balance calibration and is also used to prove whether the configured matrix is valid or not. The model weight tare system is installed to nullify weight. The role of jacking system, located inside of balance, is to effectively lock the balance during model installation/removal and protect the load cells and flexures from external forces.

Evaluations of Tare and Interference

Model support systems and fairing affect the air flow about the model, so called interference, and have a certain amount of drag for bayonet and pitch-rod, so called tare. To eliminate these unwanted effects on model or extract pure forces and moments acting on the model, the image method is generally used[3].

The procedure of the image method is as follows;

- The first run is performed with model installed in normal position(Fig. 4). The measured aerodynamic forces and moments data include tare and interference as well as forces and moments on the model. Eq. (1) is the expression for drag measured in this configuration. Other components can be expressed similarly.
- The second run is done with model installed as inverted position(Fig.5) with the image bayonets. The image fairings are attached to the ceiling turntable. The measured data include not only the case of first run but also tare and interference of image bayonets and fairings.(eq. 2)
- Final run is performed with the image bayonets and fairings removed from the inverted model(Fig. 6). The acquired data can be expressed as eq. (3).

$$D_N = D_{nM} + D_{bB} + I_{bB/M} + I_{bF/M} \quad (1)$$

$$D_{Ii} = D_{iM} + D_{tB} + I_{tB/M} + I_{tF/M} + D_{bB} + I_{bB/M} + I_{bF/M} \quad (2)$$

$$D_I = D_{iM} + D_{tB} + I_{tB/M} + I_{tF/M} \quad (3)$$

where,

D_N : measured drag in Normal position
D_I : measured drag in Inverted position
D_{Ii} : measured drag in Inverted position with image
D_{nM} : drag of Model in normal position
D_{iM} : drag of Model in inverted position
D_{bB} : drag of bottom Bayonet attached
D_{tB} : drag of top Bayonet attached
$I_{bB/M}$: Interference of bottom Bayonet on Model
$I_{tB/M}$: Interference of top Bayonet on Model
$I_{bF/M}$: Interference of bottom Fairings on Model
$I_{tF/M}$: Interference of top Fairings on Model

The actual model drag is determined in the following manner. The effects of fairings and supports on the lower surface of the model is obtained by subtracting results of inverted runs, that is eq.(2)-eq.(3). Then the actual drag is obtained by subtracting the difference of eq.(2) and eq.(3) from eq.(1).

Fig. 4. Normal Installation

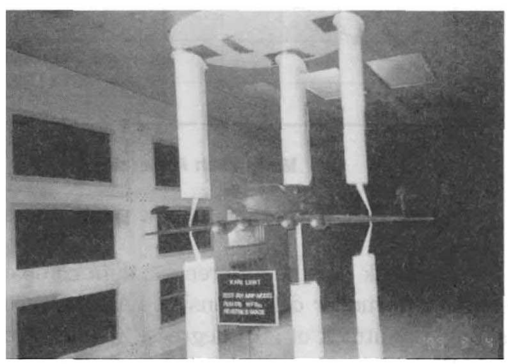

Fig. 5. Inverted with Image System

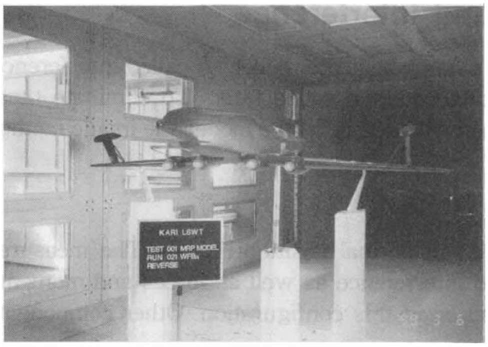

Fig. 6. Inverted Installation

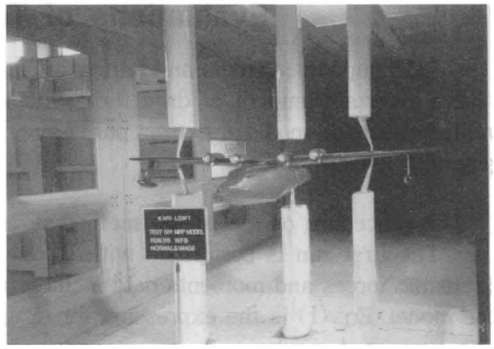

Fig. 7. Normal with Image System

Another important feature of the image test is to measure flow alignment to the model. Since most of the tunnel flow is not perfectly parallel to the ceiling and floor-lines, one should check the actual flow angularity (up-flow or down-flow) to the model. This is accomplished by performing normal and inverted runs with image system[3], and Fig. 7 shows the normal model installation with image system. To reduce model installation time related with image system, the run-log should be well organized.

Results and Discussion

To compare test results, the dynamic pressure in test section of KARI LSWT was maintained the same value as GLM tunnel(2,700 Pa), and the acquired data was only corrected for tare and interference and flow angularity. Fig.8 shows lift coefficient versus angle of attack when the model has the basic configuration that is, wing and body. Two lift curves have identical slope and the same lift coefficient at zero angle of attack. Fig. 9 shows a drag polar when MRP model were assembled to have wing, body, vertical and horizontal tails. The drag coefficient at the same lift coefficient shows large difference between GLM tunnel and KARI LSWT.

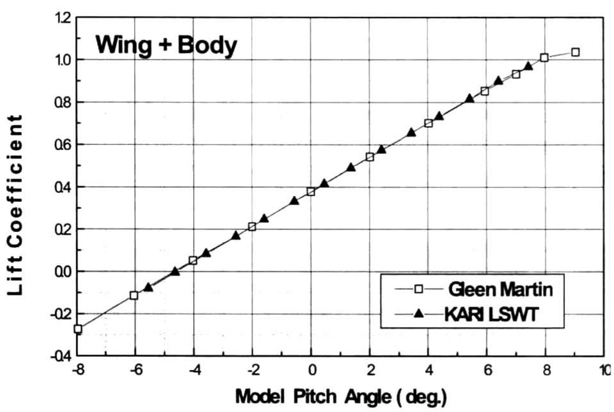

Fig. 8. Lift Coefficient vs. pitch angle

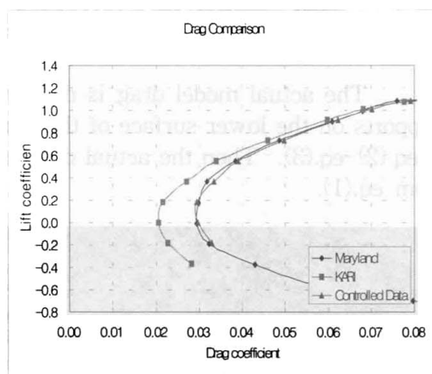

Fig. 9. Drag polar

To check out the differences, data comparisons were done for all the configurations including elevator and rudder deflections[4]. All the results showed 90 counts difference for minimum drag, and angle of attack of -0.4 degrees. The controlled data of fig. 9 was obtained by adding 90 counts to KARI initial values and 0.4 deg. to the angle of attack of KARI test. Probable causes of the differences of the data are as follows;

- KARI LSWT might have used a different reference plane for the pitch angle of model in normal or inverted tests from GLM tunnel.
- The test result of GLM tunnel showed less tare and interference even though longer and slender bayonets were used compared to KARI LSWT[1]. GLM tunnel might have not subtracted the tare and interference.
- Since forced boundary layer transition were not applied to both tests, the difference in turbulent intensity(0.21% for GLM, 0.07% for KARI) of both facilities might have effects.

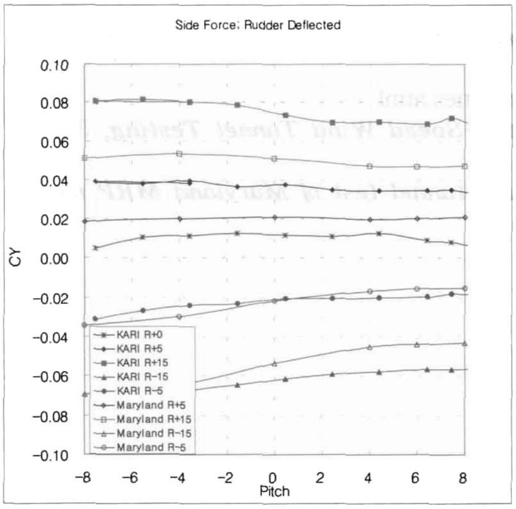

Fig. 10. Side Force vs. pitch angle

Fig. 10 shows side force variation based upon rudder deflections. The results indicate that the KARI LSWT may have a slightly yawed flow. Another possibility is that installation of the vertical tail is not strong enough to sustain wind load because bolt connected fuselage and vertical tail was loosened. Fig. 11 shows pitching moment variation with respect to pitch angle. The measured results are reasonably well matched. Fig. 12 shows the drag build up by adding model component one by one. The basic configuration starts from wing, body and vertical tail. The horizontal tail, wing pod, and domes were added. The results shown in Fig. 12 were not corrected for 90 count drag difference and -0.4 degree angle of attack.

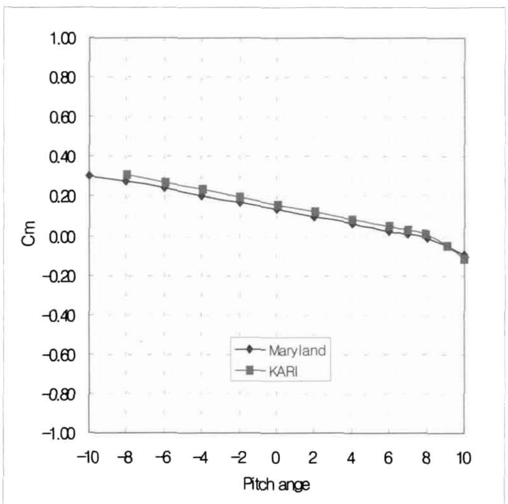

Fig. 11. Pitching Moment vs. Pitch angle

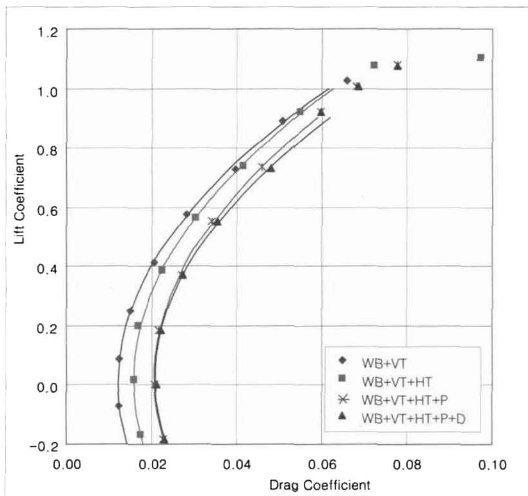

Fig. 12. Drag build-up for MRP Model

Conclusions

The force and moment measurements on MRP model of GLM tunnel were performed as a part of the wind tunnel final performance test of KARI LSWT. The lift, side force and moments except drag force showed very good agreement between two facilities. The difference in drag component may be due to misinterpretation of interference and tare drag in GLM tunnel during data processing.

Acknowledgement

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