Wind Tunnel Testing Productivity at KARI LSWT

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Abstract

Productivity enhancement program of wind tunnel testing has begun at Korea Aerospace Research Institute Low Speed Wind Tunnel (KARI LSWT). A previous test record of a canard airplane model was adopted to examine the current status of wind tunnel testing efficiency. The time consumed to perform testing activities from the model preparation to data collection was broken down and the results were compared with those of the recent Boeing low speed test result. The efforts to improve the wind tunnel productivity consisted of the installation of mini crane underneath of test section, fabricating lift device for image fairings, model configuration changing rigs and the modifications of external balance system. Time reductions for changing strut interface platform and installation of image fairings. These effects showed more than 70% improvement over the previous test time. Integration of the new and modified systems will improve productivity of wind tunnel testing in KARI LSWT.

Key Word : Wind Tunnel, Productivity Enhancement, Model Installation Tools

Introduction

A significant competitive advantage of the aerospace industries was gained by effectively reducing the airplane development time in recent years. Wind tunnel test cycle, hereafter defined as the time between delivery of model to the wind tunnel and removal of model from test section, must also be reduced to fulfil customer's requirement.

NASA Langley Research Center(LaRC) recently consolidated wind tunnel facilities into one branch and has pursued the aim such as fulfillment of customer requirements, the improvement of tunnel productivity, reduction in testing cost and time and enhancement of data quality[1]. To improve the productivity of National Transonic Facility(NTF) in LaRC[2], the special task force teams were organized, and a careful research of the wind tunnel testing activities was performed. The polars per user occupancy hours(UOH) as a result of tunnel re-engineering activity were significantly increased by reducing unscheduled downtime and some improvements on controls, fan drive and pressure storage systems. A recent paper by Payne[3] illustrated a typical occupancy statistics of Boeing low speed tests and showed a recommended level of productivity. In addition, Payne[3] discussed crucial issues in wind tunnel testing such as repeatabilities of measured data, accuracy requirements for angle of attack, dynamic pressure and pressure measurement.

This paper discusses the result of productivity for the selected wind tunnel test based on the canard airplane model, which was done in the middle of 2000, and introduces some terminologies to describe activities in the process of testing. The current productivity in KARI LSWT is compared with Boeing low speed test, and some efforts to enhance productivity are also discussed.

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Break-down of wind tunnel testing activities

Wind tunnel tests for the various objects such as airplane model, A/C cooling units, high speed train and motorcycle have been performed at KARI LSWT. Time requirement for the model installation, fan operation, data acquisition, model configuration change and removal of model during the wind tunnel test cycle are all recorded in recording sheet shown in Fig.1. Also, variations of dynamic pressure and fan RPM are recorded to evaluate tunnel operating condition.

Wind Tunnel Testing Recording Sheet

Run No.		Target pressure =	Pa
Model Configuration			
Model Installation		normal	inverted
Image System		yes	no
Comments			

Working Activities

Arrival on Control Room	A.M. P.M.	
Instrument Check(Fan, CT, bal.,Testview	A.M. P.M.	
Pre-load Start	A.M. P.M.	
Wind-On Time	A.M. P.M.	
Target Pressure in T/S	A.M. P.M.	
Wind-Off(Fan-Off) Time	A.M. P.M.	
Zero Pressure in T/S	A.M. P.M.	
Arrival on Model	A.M. P.M.	
Start of Model Configuration Change	A.M. P.M.	
End of Model Configuration Change	A.M. P.M.	

AOA	step	T/S Pres.	Set RPM	Remark
0	0			
0	0			
-4	457			
-2	229			
0	0			
2	-229			
4	-458			
6	-688			
8	-917			
9	-1031			
10	-1145			
11	-1259			
12	-1373			
13	-1486			
14	-1599			
15	-1712			
16	-1825			
18	-2049			
20	-2271			

Date
Recorded by

Fig. 1. Wind tunnel test recording sheet

1. Activities in Wind Tunnel Testing

The frequently asked question from the customers before wind tunnel test is how many number of polars per hour? or how many polars can be produced in a day? However, the above statement did not tell the whole story of wind tunnel productivity. There will be huge difference in testing results according to the wind tunnel testing environment such as subsonic or transonic and consisting number of data points in a polar. Polars per occupancy hour and polars per fan-on hour are the well-known and meaningful indicators to explain wind tunnel productivity and suggested in reference 3.

Prior to the productivity estimation at KARI LSWT by using above mentioned factors, one should carefully consider which parameters should be used to represent wind tunnel test activities from the model installation to the removal of model from test section. The selected parameters which might have strong effects on productivity are introduced in here and defined to help understand wind tunnel testing activity.

Model support installation time ; When the model arrives in KARI LSWT, it takes a certain amount of time to install model supporting strut, strut fairings, pantograph and image fairings.

Model repair time ; When an unexpected model modifications occur especially in canard airplane model test due to attachment failure for the image pitch-rod and interference between canard and fuselage, some efforts should be devoted to fix the model.

Model configuration changing time ; Time for changing model control surfaces and canard incidence blocks for each run. Model configuration changing time also includes weight tare run time since data collection is done after model configuration change without fan operation.

Start-up time ; This represents the time interval when the facility staff starts checking model installation, tunnel circuit and operation conditions of subsystems before the pre-load.

Pre-loading time ; Before taking forces and moments data, air-load is applied on the model about 5 or 6 minutes.

Fan-on time ; The time between the start of fan and end of fan operation until dynamic pressure in test section reaches zero value.

Facility down time ; This indicates time that the operator could not conduct test due to several causes such as fan vibration trip, systems failures in control and data acquisition.

Lost time ; When the model is ready to test, the facility staff should also be ready. But for some reason test can not be performed.

The itemized time consumption in wind tunnel test activities is illustrated in Table 1 for the selected working days. All of the informations in Table 1 are recorded by test engineer on the recording sheet shown in Fig. 1.

Table 1. Testing activities and required time

working day	4/24	4/29	5/4	5/10	5/30
model support installation	3.00				
start up(A.M.)		0.50	0.50	0.42	0.67
start up(P.M.)		0.42	0.45	0.50	0.37
model repair					
pre-load		0.08	0.13	0.10	0.08
Fan-on		2.65	1.38	2.95	1.98
number of runs		8	3	11	6
weight tare run		0	1	0	2
weight tare run time		0.00	0.28	0.00	0.40
number of flow Viz.					1
preparation for flow Viz.					0.67
fan-on time for flow Viz.					0.67
control surface changing		1.87	0.38	2.32	1.97
installation direction			2.50	0.00	
discussion on results			1.18		
idle time between runs		0.28	0.25	0.42	0.45
preparation for sealing test				0.42	
sealing Daq.				0.43	
lost time(P.M.)	5.00	0.97	0.42	0.40	0.47
lost time(A.M.)		0.22	0.50	0.03	0.28
fan failure(powercell, trip)					
Testview problem					
actual working hour	8.00	6.99	7.98	7.98	8.00
Working Hours	8	7	8	8	8

Table 2. Summary of classified activities

Activities	Occupied Hours	Percentage(%)
Model Installation	40.24	24.24
Start-up time	21.01	12.66
Fan-on Time	40.5	24.4
Model Change Time	30.45	18.34
Facility Down Time	3.55	2.14
Lost Time	30.25	18.22
Total Hours	166	

To analyze the collected informations more effectively, all the activities are classified in six items as shown in Table 2. Model installation is consisted of the installation of model support, model repair, changing of model installation direction itemized in Table 1. Start-up time is the sum of A.M. and P.M. start-up time. Fan-on time includes pre-load, fan-on, flow visualization and slot sealing test. Model change time is consisted of weight tare run time, preparation of flow visualization, change of control surfaces, preparation of slot sealing test. Facility down time implies discussion on results, fan failure and Testview problem. Lost time is the summation of with both A.M. and P.M. lost time and idle time between runs.

2. Productivity of KARI LSWT

We summarize in Table 3, the current wind tunnel testing productivity at KARI LSWT compared with the low speed test results of Boeing[3]. Two indicators, polar/wind tunnel occupancy time and polar/fan-on time, were selected for comparison. The former presents overall testing efficiency including model change time and the latter shows the efficiency of tunnel controllability and data acquisition.

Table 3. Productivity comparisons between KARI LSWT and Boeing[3].

Item	KARI LSWT	Boeing
Polars/occupancy time*	0.77	1.5
Polars/fan-on time	3.1	3
Fan-on time	24.4 %	50 %
Facility down time	2.14 %	5 %
Start-up time	60.04 minute	less than 1 hour
Model Change time	38 minute	45 minute

note : *occupancy time = tunnel occupancy time-facility down time

Each pitch sweep at KARI LSWT consisted of 19 data points, and the test was conducted over an angle-of-attack range from -4 to 20 degrees. Polars/occupancy time was obtained by dividing the total run such as force-moment, flow visualization and weight tare run by occupancy time. Model change time was obtained by dividing model change time in Table 2 by the number of runs except weight tare runs.

Polars/fan-on time at KARI LSWT is acceptable and shows good status in tunnel control and data acquisition efficiency. However, polars/occupancy time shows a poor result, and it must be improved. To enhance current productivity at KARI LSWT and survive in tough competent environment, the fan-on time should be dramatically increased. The elaborated analysis for model installation especially changing model configuration from normal to inverted or vice versa, start-up, lost time and data acquisition process was conducted by evaluating the time required to perform each of the activity.

Efforts for Productivity Enhancements

Some efforts to improve wind tunnel testing productivity at KARI LSWT were started in the middle of 2000 as a part of national research laboratory(NRL) program. The first step for productivity enhancement was manufacturing new tool to reduce model installation time and modification of the external balance system.

1. Improvements on the model installation issues

The direction of the strut interface platform[7], which had T-shape, must be changed depending upon the relative position of the pitch-rod to the wing bayonets. To change its direction, detachment of clamps connected test section and tunnel circuit, removal of ladder in balance, re-location of model lifter, disengagement of signal and control cables for balance and PTS(Probe Transverse System) should be done first. Thereafter test section, weighted around 120 ton, could be moved toward parking hall side to change strut interface platform. And then overhanging crane was moved just on top of the balance and direction of strut interface platform was rotated by using slings. The amount of time consumption to change platform direction took about one day by four engineers.

The new small crane underneath of test section shown in Fig. 2 was designed and manufactured to effectively use space around balance system, and it can lift up to 2000 kg weight. By using that crane, the time required to change strut interface platform were significantly reduced to less than an hour.

Interference effects, which was caused by interaction between model support systems and fairing and model itself, and drag tare, which was represented an extra amount of drag due to bayonets and pitch-rod, must be corrected to extract pure forces and moments acting on the model. The elimination of those effects can be done by adaption of image method[7]. Installation or removal of image fairing and removal of cover-plates in ceiling turntable took 5 hours by three engineers. There was a good possibility of the model damage, since the removal of cover-plates was normally done in model installation to reduce the installation/removal time. A new tool for image fairings and cover-plates shown in Fig. 3 was fabricated, and it reduced time consumption and man-power requirement less than 70% and 30% respectively.

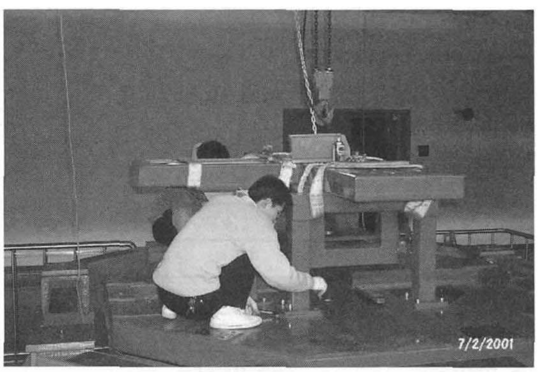

Fig. 2. New crane installed beneath the test section

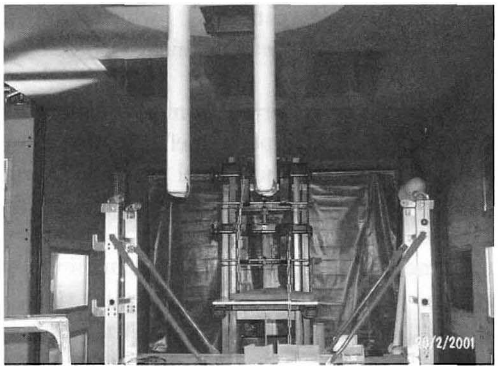

Fig. 3. Tool for image fairings and cover-plates

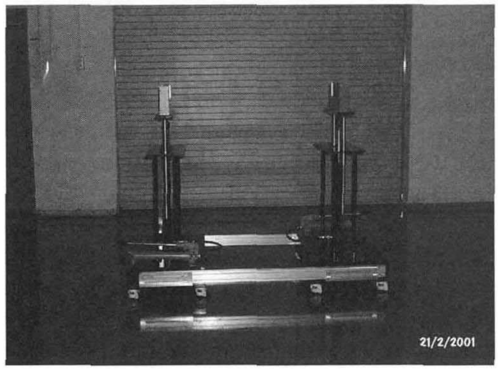

Fig. 4. Model rotation tool

The change of the model installation condition from normal to inverted or vice versa could not be performed inside of test section since the span of model was 2.6 m and a proper tool did not exist. The only way one could do was removing model from the test section and changing installation condition in model preparation room. Before the removal of model, the fuselage parts had to be disassembled for model rotation on the surface plate. Since the fuselage parts must be bolted again and sealed cavity areas using aluminium tape and red wax, it took more than one day.

The new tool shown in Figure 4 eliminates the time necessary to disassemble fuselage parts and move model to the model preparation room. The major benefit of new tool is that the possible causes of model damage by moving model around are reduced, and hopefully it will reduce model installation time.

2. Reduction in Lost and Start-up Times

The lost and start-up times possess 31% of overall tunnel occupancy time. The occurrence of lost times were not clearly understood at this moment. However, it might be related with the mistakes in time management and in the recording process. The lost time could be definitely reduced if the test engineer paid more attentions in schedule management and recoding of each activity during the test. The current status of start-up time showed almost identical level of time consumption compared with Boeing's statistical results[3]. · It is necessary to keep the start-up less than an hour. The effort to reduce start-up and lost times will be continuously conducted since it will increase the fan-on time.

3. Reduction in Data Acquisition Time

The time required to take one point in a polar is 52 seconds in current situation. To rummage data acquisition process, recording sheet in Fig. 1 was carefully reviewed and data acquisition sequences were repeated several times. The activities during data recording could be categorized as follows: dynamic pressure control, balance load signal recording, model attitude control such as angle-of-attack or sideslip and, data pattern observation before model attitude change.

Tunnel operator normally changed fan RPM a few times to maintain target dynamic pressure, which was 1504 Pa in the canard model test, as the angle-of-attack of the model varied, and the standard deviation of dynamic pressure was 4.3 Pa resulting from manual fan operation. The load signal recording time was set to conservative value of twenty seconds. A few seconds were delayed to settle down load signals after completing pitch motion. Data pattern observation time was normally needed before moving to next model positions.

The average times for one data point was 17 and 20 seconds for transport and military airplane model, respectively, at MicroCraft Low Speed wind tunnel[8], which finished modernization of DAQ, model positioning. It was no doubt that the data acquisition process at KARI LSWT must be improved.

The first step in the modification of data acquisition process started from the analysis of load signal and control system of balance was performed by KARI personnel. It was found that the EMI caused signal fluctuations of the balance output after the model attitude change, and necessary modification on signal and cable paths were done by KARI and Aerotech, supplier of the balance.

Next effort was focused on the data recording time. The upgraded data sampling rate and modification of viscous damping in balance system showed a promising result such as shown in Fig. 5, and 10 seconds of data recording was already exceeded more than 95% of confidence level. Therefore the data recording time will be set less than 10 seconds from now on.

The further improvement of acquisition process will be model attitude control. The pitch positioning of model was done by key-in the number, so called step value in Fig. 1 corresponding a certain angle-of-attack. Since the modification on balance signal paths does not generate EMI noise, the automatic positioning of the model could be adapted to save time.

The PC for the tunnel operational informations and data acquisition could be used to provide automatic pitch control functions. The modification of computer program is underway.

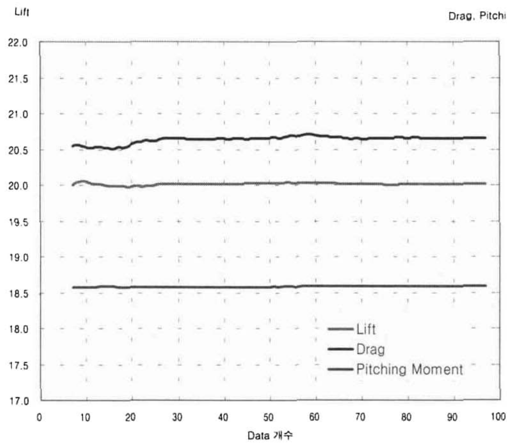

Fig. 5. Load signal variation according to number of data points

4. Model Change Time

The efficient model changes depend on how fast the customer and test engineer can access the model and check the model, how many engineers can systematically work in the test section, and how easy the model part itself can change. The model access time presents time interval between final zero recording to reaching the model inside of test section. Normally, the model change was done by four engineers; two customers and two KARI personnel including test engineer. Model change time in Table 3 contained lots of activities mentioned in section 2.1 and showed 38 minutes which is less than Boeing result. However, the actual time to change only model control surface took less than 10 minutes based on the recording sheet.

To reduce model change time, the careful inspection of a small part such as bracket should be done before the test. In KARI LSWT, for example, the attachment position of bracket, which connected canard and elevator, was not engraved when the bracket arrived on site. The initial runs were done without much attention on the bracket direction. After a few runs, the pitching moment patterns in a certain elevator deflection case are slightly different from the previous results shown in Fig. 6. The customer and tunnel operator discussed this problem more than two hours, and finally found that one side of bracket was attached in wrong direction.

The model change time at KARI LSWT has already reached some level of satisfaction. However, the chance of further improvements still exists. Model should be designed and fabricated easy to install and change, and the attachment directions of parts and brackets are easy to notice.

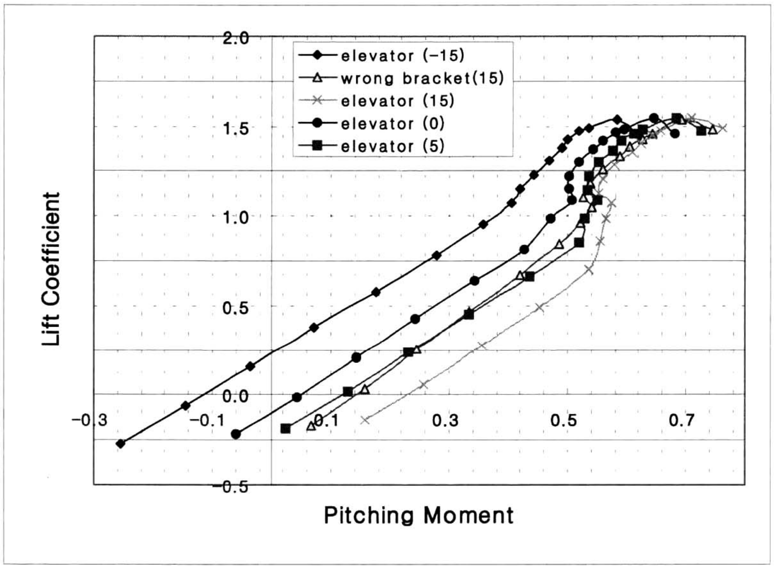

Fig. 6. Lift coefficient and pitching moment

Conclusions

Productivity of the wind tunnel test at KARI LSWT has been examined for a selected airplane model test. To evaluate time consumed during wind tunnel test, activities from the installation of model to removal of model in test section were categorized and analysed. Compared with the Boeing's result for low speed test, the polars per fan-on time showed acceptable level of satisfaction, but polars per tunnel occupancy time were way behind the recommended level. To improve current productivity toward world class facility, the efforts first of all were concentrated on the preparing new tools for the model configuration change and fairings installation. The load signal fluctuations of balance after attitude change were resolved by changing cable routings, and delay time was reduced about 5 seconds for each data point of a polar. Time Reductions for changing strut interface platform and installation of image fairings already showed more than 70% improvement. Integration of the new and modified systems will improve productivity of wind tunnel testing in KARI LSWT.

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