NASA/TM- -1998 208264

Comparison of The Aerodynamic Characteristics of Similar Models in Two Size Wind Tunnels at Transonic Speeds

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Abstract

The aerodynamic characteristics of two similar models of a lifting body configuration were run in two transonic wind tunnels, one a 16 foot the other a 14-inch and are compared. The 16 foot test used a 2% model while the 14-inch test used a 0.7% scale model. The wind tunnel model configurations varied only in vertical tail size and an aft sting shroud. The results from these two tests compare the effect of tunnel size, Reynolds number, dynamic pressure and blockage on the longitudinal aerodynamic characteristics of the vehicle. The data accuracy and uncertainty are also presented. It was concluded from these tests that the data resultant from a small wind tunnel compares very well to that of a much larger wind tunnel in relation to total vehicle aerodynamic characteristics.

Nomenclature

Alpha, α	angle-of-attack
Beta, β	angle-of-sideslip
C_A	axial force coefficient
C_N	normal force coefficient
C_M	pitching moment coefficient
L_{ref}	reference length
S_{ref}	reference area
Xmrp	moment reference point
Subscript o	at zero degrees angle-of-attack

Introduction

When a new customer entertains the notion of testing at a relatively small size wind tunnel facility they sometimes have misconceptions about the quality of the data the facility will produce. The Mach number range of the small facility normally surpasses that of the larger facilities, Mach 0.2 to 5.0, as compared to 0.2 to 1.5 for a transonic tunnel. This alleviates the need to test at multiple tunnels to obtain data at the full Mach range. The operational cost of the small facility or the cost past on to the customer is usually much lower by at least multiple factors. In addition the small tunnel is in general more readily available for testing or has a shorter waiting list for tunnel time though this is not always the case. It should be noted that a small tunnel cannot test the larger highly detailed models a large tunnel can test or the combined pressure/force tests a large tunnel uses due to size limitations on the models. There are sometimes concerns about data quality in relation to blockage effects, flow quality, and wall interference. These concerns are in the most part are unfounded and this paper serves to better alleviate these concerns by showing the data derived from two very different size facilities the NASA LaRC 16 foot transonic wind tunnel and the NASA MSFC 14-inch trisonic wind tunnel for a lifting body configuration.

Facilities

NASA LaRC 16 ft transonic wind tunnel

The Langley 16-foot transonic tunnel is a closed-circuit single-return atmospheric wind tunnel that has a slotted octagonal test section with continuos air exchange. The wind tunnel speed can be varied continuously over a Mach range from 0.1 to 1.3 at angles of attack up to 25 degrees. Speeds up to Mach 1.05 are obtained with the tunnel main drive fans: the addition of test section plenum suction is used for speeds above Mach number of 1.05. The slotted octagonal test section nominally measures 15.5 feet across the flats. The usable test section length is 22 feet for speeds up to Mach 1.0 and 8 feet above Mach 1.0. The tunnel operational conditions are shown in table I.

Mach	Reynolds Number	Dynamic Pressure
.3	1.96 x 10^6/ft	.856 lbs/in^2
.6	3.35	2.87
.8	3.7	4.26
.9	3.8	4.9
.95	3.8	5.15
1.05	3.8	5.6
1.1	3.8	5.79
1.15	3.8	5.95

Table I: 16 Foot Wind Tunnel Operating Conditions

NASA MSFC 14x14-inch trisonic wind tunnel

The MSFC 14 x 14 Inch Trisonic Wind Tunnel, is an intermittent blowdown tunnel which operates by high pressure air flowing from storage to either vacuum or atmosphere conditions. The transonic test section provides a Mach number range from 0.2 to 2.0. Mach numbers between 0.2 and 0.9 are obtained by using a controllable diffuser. The Mach range from 0.95 and 1.3 is achieved through the use of plenum suction and perforated walls. Each Mach number above 1.30 requires a specific set of two-dimensional contoured nozzle blocks. A solid wall supersonic test section provides the entire range from 2.74 to 5.0 with one set of movable fixed contour nozzle blocks. Downstream of the test section is a hydraulically controlled pitch sector that provides the capability of testing up to 20 angles-of-attack from -10 to +10 degrees during each run. Sting offsets are available from obtaining various maximum angels-of-attack up to 90 degrees. Table II lists the relation between Mach number, dynamic pressure and Reynolds number per foot for the 14-inch TWT.

MACH NUMBER	REYNOLDS NUMBER	DYNAMIC PRESSURE
0.20	1.98×10^6/FT	0.60 lbs/in^2
0.30	2.8	1.30
0.60	4.7	4.36
0.80	5.5	6.47
0.90	5.9	7.36
0.95	6.2	7.76
1.05	6.1	8.48
1.10	6.2	8.76
1.15	6.2	8.99
1.25	6.2	9.31

Table II: 14-Inch Wind Tunnel Operating Conditions

Facility Comparisons

The LaRC 16 ft tunnel has a test section of approximately 16ft x 16ft neglecting the corners, while the MSFC 14in tunnel has a square test section of 14in x 14in. The following two figures show a comparison between the two tunnels for Reynolds number per foot verses Mach figure 1 and Dynamic Pressure verses Mach, figure 2. To convert Reynolds number per foot to total Reynolds number multiply the Reynolds number per foot by the model length.

Model Geometry

The geometry for these tests was that of a lifting body configuration with fins, vertical tails, and body flaps. The 16ft test used a 2% model while the 14-Inch test used a 0.7% model. The models were identical except for the following differences. The vertical tail size varied between the models and the 2% model had what was termed a sting shroud attached to the aft end. The 2% model had a 10%, scaled, larger vertical tail by planform area than the 0.7% model The respective reference model dimensions for the two models are shown in table III.

	2% Model	0.7% Model	
Sref	92.6208 in^2	3.275 in^2	
Lref	15.1872 in.	5.296 in	
Xmrp	10.02355in.	3.494 in	66% Full Scale

Table III: Model Reference Dimensions

Tests

LaRC

The baseline testing was done over the Mach range of Mach 0.25 to 1.2 at 12 selected Mach numbers. These Mach numbers were 025, 0.30, 0.35, 0.4, 0.6, 0.8, 0.9, 0.95 1.05, 1.1, 1.15, and 1.2. The model was tested at angle-of-attack ranges from -10 degree to +24 degrees at zero sideslip.

MSFC

Testing was done over the Mach range of Mach 0.3 to 5.0 at 13 selected Mach numbers. These Mach numbers were 0.3, 0.60, 0.80, 0.90, 0.95, 1.05, 1.10, 1.15, 1.20, 1.46, 2.74, 3.48, and 4.96. Additional runs were made at other Mach numbers for comparison purposes. The model was tested at angle-of-attack range from -4 degree to +16 degrees at zero degrees sideslip. The reference aerodynamic axis system used for both tests is shown in figure 3. A photograph of the model mounted in the 14-inch trisonic wind tunnel is shown in Figure 4.

Comparison of Results

The longitudinal data of pitching moment coefficient, normal force coefficient, and axial force coefficient are compared for the Mach range of 0.3 to 1.15. Data for Mach numbers of 0.3, 0.8, 0.95, and 1.15 are shown in Figures 5 through 16. It can be seen from these data that the normal force coefficient data through the Mach range didn't really vary between the two tests. The pitching moment coefficient varied at negative angles for Mach 0.3, showed no variance at Mach 0.8, a slight curve shift at Mach 0.95, and a small variance at the higher angles-of-attack at Mach 1.15. The axial force coefficient showed a slight incremental trend shift at Mach 0.3, no shift at Mach 0.8, and a small incremental trend shift at Mach 0.95 and 1.15.

Effect of vertical tail size

One of the main differences between the two models was the size of the vertical tails. The effects of tail size on the vehicles longitudinal aerodynamic characteristics are presented. The two size vertical tails were tested on the 0.7% model and the data is presented in Figures 17 and 18 for normal force and pitching moment coefficient for a representative Mach number of 0.80. The difference in tail size was approximately 10%, with this increase in size shown on the 2% model. From this data it is seen that tail size has only a small effect on the longitudinal aerodynamic of the vehicle. A very minor change is seen in both the axial force and the pitching moment. The change in tail size imparts only a small moment due to the relatively short moment arm of the tails.

Effect of Sting Shroud

The second difference between the two models was the addition of what was called a sting shroud on the 2% model. This cylindrical attachment was mounted to the base of the model and was 2.125 inches in diameter and 1.8 inches long, 2% model dimensions. The attachment was mounted around the sting out the center of the model base through the aerospike engine. Testing was done on the 0.7% model with both the sting shroud on and off to determine its effect on the vehicles longitudinal aerodynamics. At the relatively small angles-of-attack of this study the sting shroud effects were very minor for all coefficients, this may not be the case at higher angles-of-attack.

Data Accuracy

The data accuracy for the two sets of data in general was based on the quoted balance accuracy which in general were assumed to be ½% of the full scale balance capacities. The quoted values for the two facilities balances are shown in tables IV and V for the LaRC Balance 840 and MSFC Balance 250 respectfully.

Show in coefficient matrix?

	Capacity	Accuracy
Normal Force	800 lb	±4.0 lb
Side Force	250 lb	±1.26 lb
Axial Force	125 lb	±.0625 lb
Pitching Moment	1600 in-lb	±8.0 in-lb
Rolling Moment	500 in-lb	±2.5 in-lb
Yawing Moment	500 in-lb	±2.5 in-lb

Table IV: LaRC Balance 840 Accuracy

	Capacity	Accuracy
Normal Force	200 lb	±0.20 lb
Side Force	107 lb	±0.50 lb
Axial Force	75 lb	±0.25 lb
Pitching Moment	200 in-lb	±0.20 in-lb
Rolling Moment	50 in-lb	±0.25 in-lb
Yawing Moment	107 in-lb	±0.50 in-lb

Table V: MSFC Balance 250 Accuracy

To obtain the balance accuracy effect on the aerodynamic coefficients, the accuracy must be converted to coefficients, then these 'error' bars can be applied to the data. The accuracy is inputted into the standard coefficient equations using the respective reference dimensions and flow conditions to obtain the 'error' bars or bands for the data. The bands on the data very greatly with Mach since the loads at the lower Mach numbers are smaller, the percent of the total loading the accuracy is are greater given the accuracy of the balance is based on total balance loads.

The models were rolled on their respective balances at the following angles; the 2% model was rolled -0.4466 degrees right fin up, while the 0.7% model was rolled -0.45 degrees right fin up. Since the models were installed level in the tunnel these rolls have a small effect on the overall data. The effect can be determined by applying the respective trigonometric function using the roll angle applied to the respective coefficient. This yields for a 0.5 degree roll angle, the normal force measured is 0.99997 of the actual force.

Conclusions

The data resultant from the two tests of similar models of varying scale in two vastly different size tunnels, 16 foot and 14 inches, shows very good agreement. This study compare the data derived from a lifting body configuration. It can be concluded from this comparison that the data resultant from a small wind tunnel in general with in the accuracy limits of the data, data repeatability and variances within both wind tunnels and models match that derived from a much larger tunnel in relation to total vehicle aerodynamic characteristics. This paper serves as a data point for future comparisons and a reference to future users.

Acknowledgments
The authors wish to thank the wind tunnel test team at Marshall, Holly Walker, Henry Brewster, James Aaron, Mindy Niedermeyer, and Alonzo Frost, and the Langley 16 Foot test team.

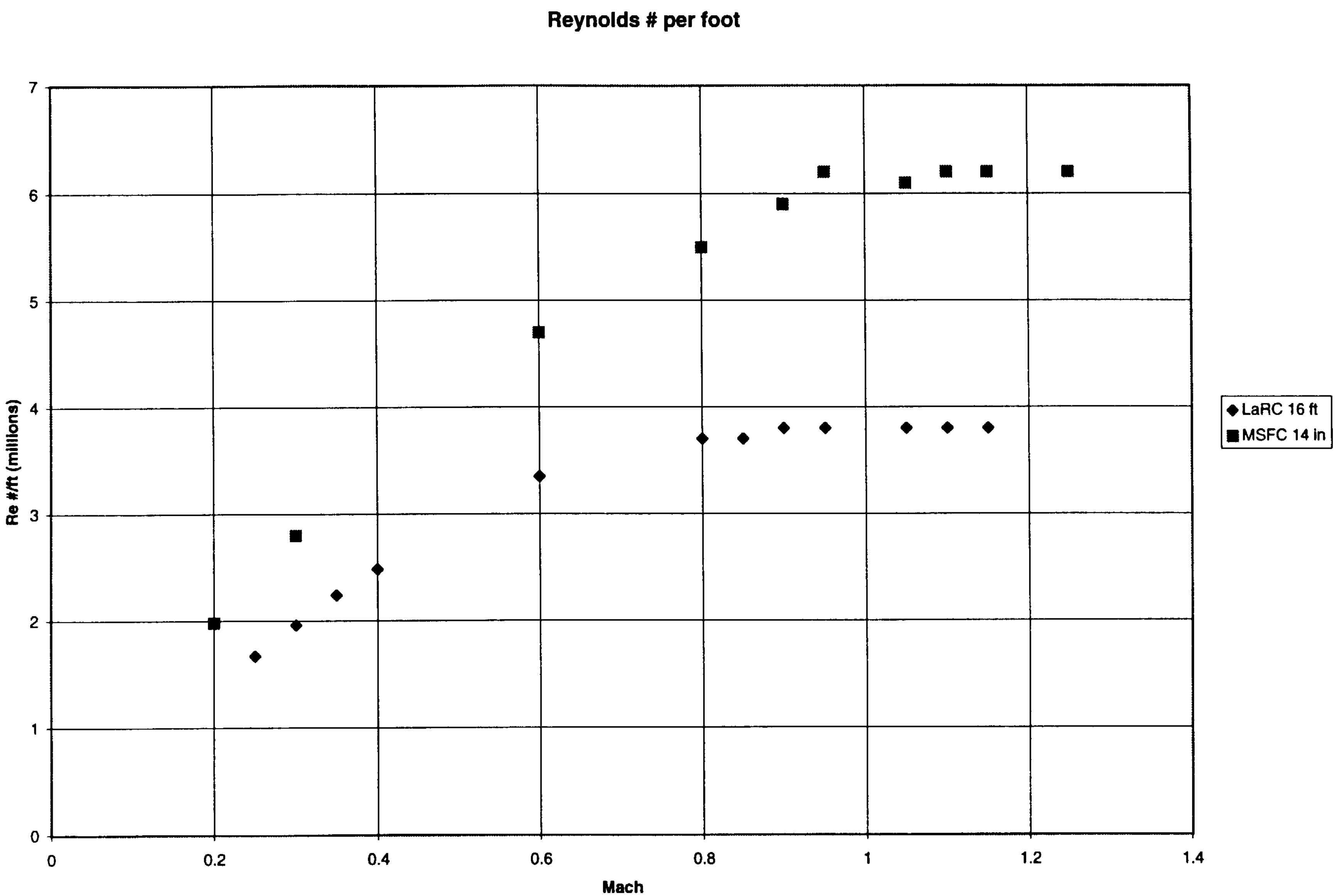

Reynolds # per foot
Re #/ft (millions)
0
1
2
3
4
5
6
7
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Mach
LaRC 16 ft
MSFC 14 in

Figure 1

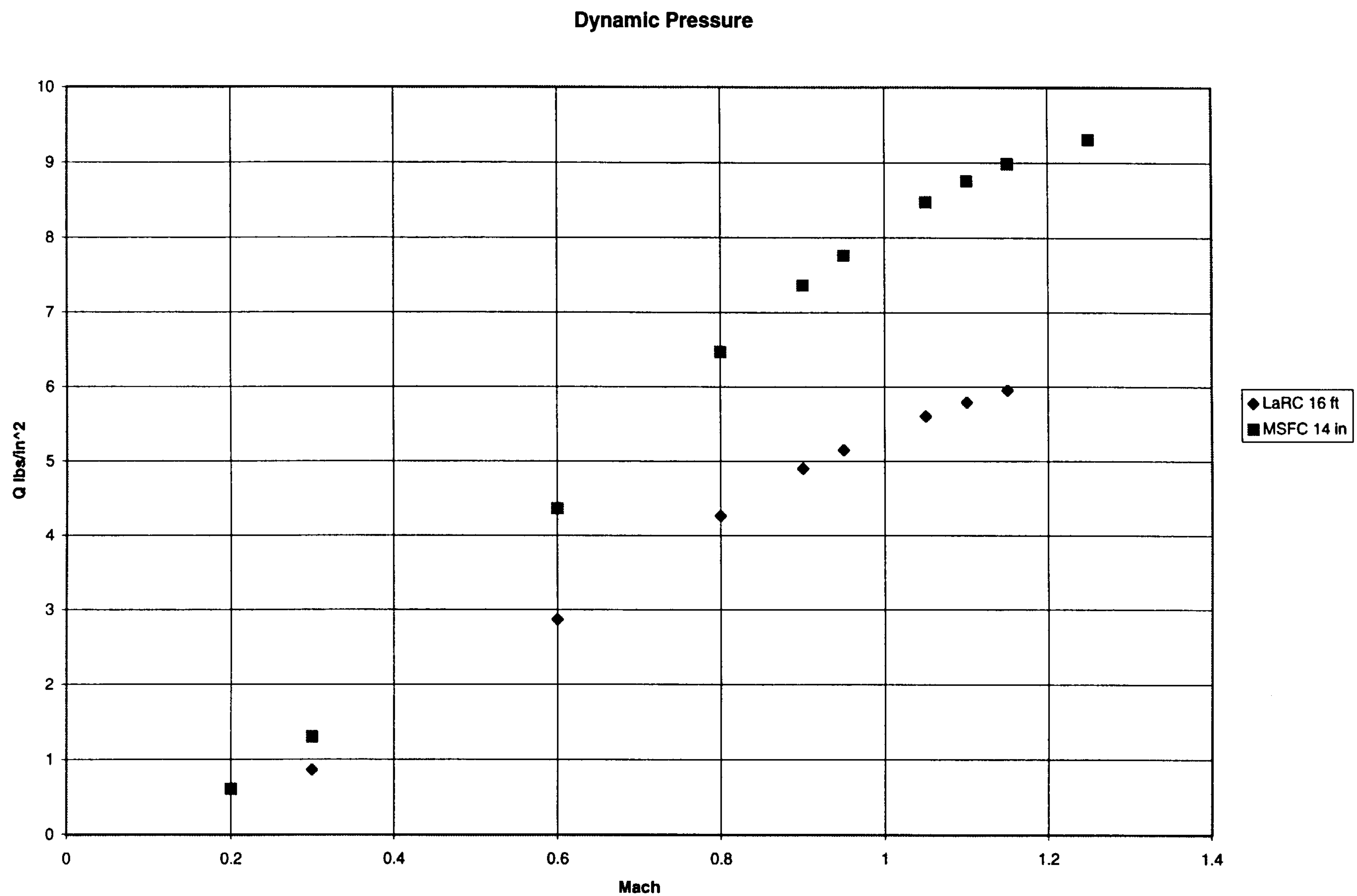

Dynamic Pressure
10
9
8
7
6
5
4
3
2
1
0
Q lbs/in^2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Mach
LaRC 16 ft
MSFC 14 in

Figure 2

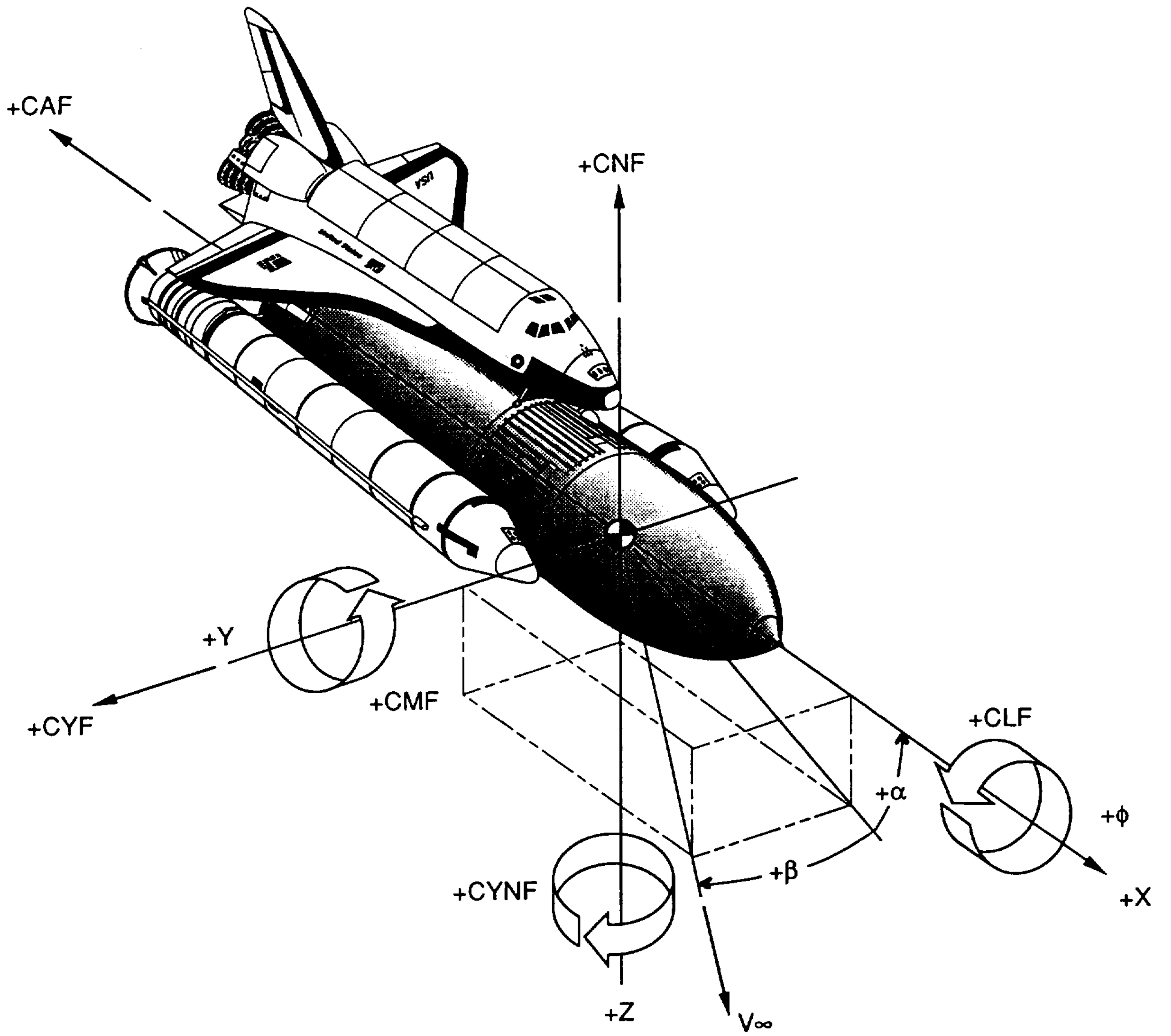


Figure 3

5-19681

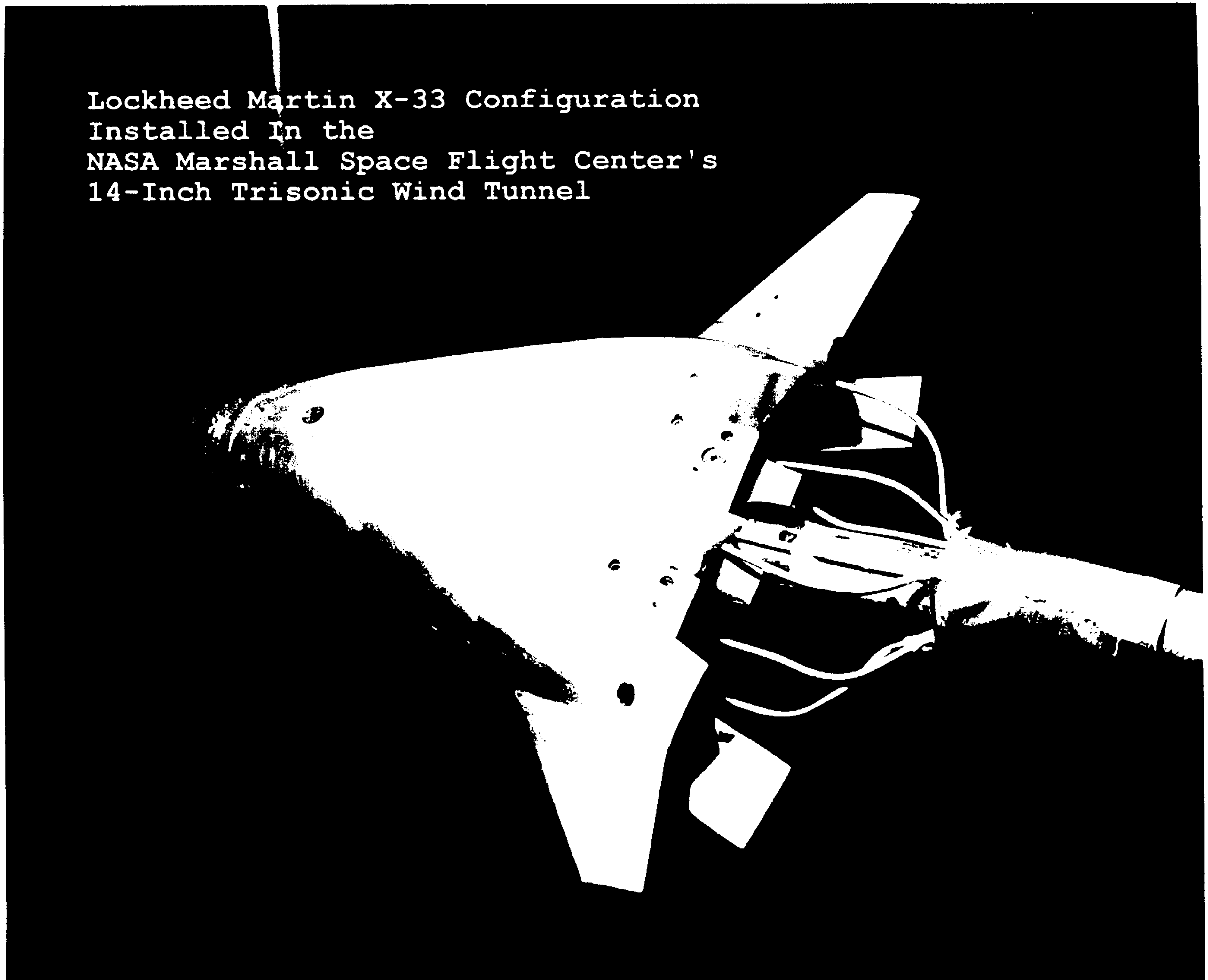

Lockheed Martin X-33 Configuration
Installed In the
NASA Marshall Space Flight Center's
14-Inch Trisonic Wind Tunnel

Figure 4

CN M 0.3

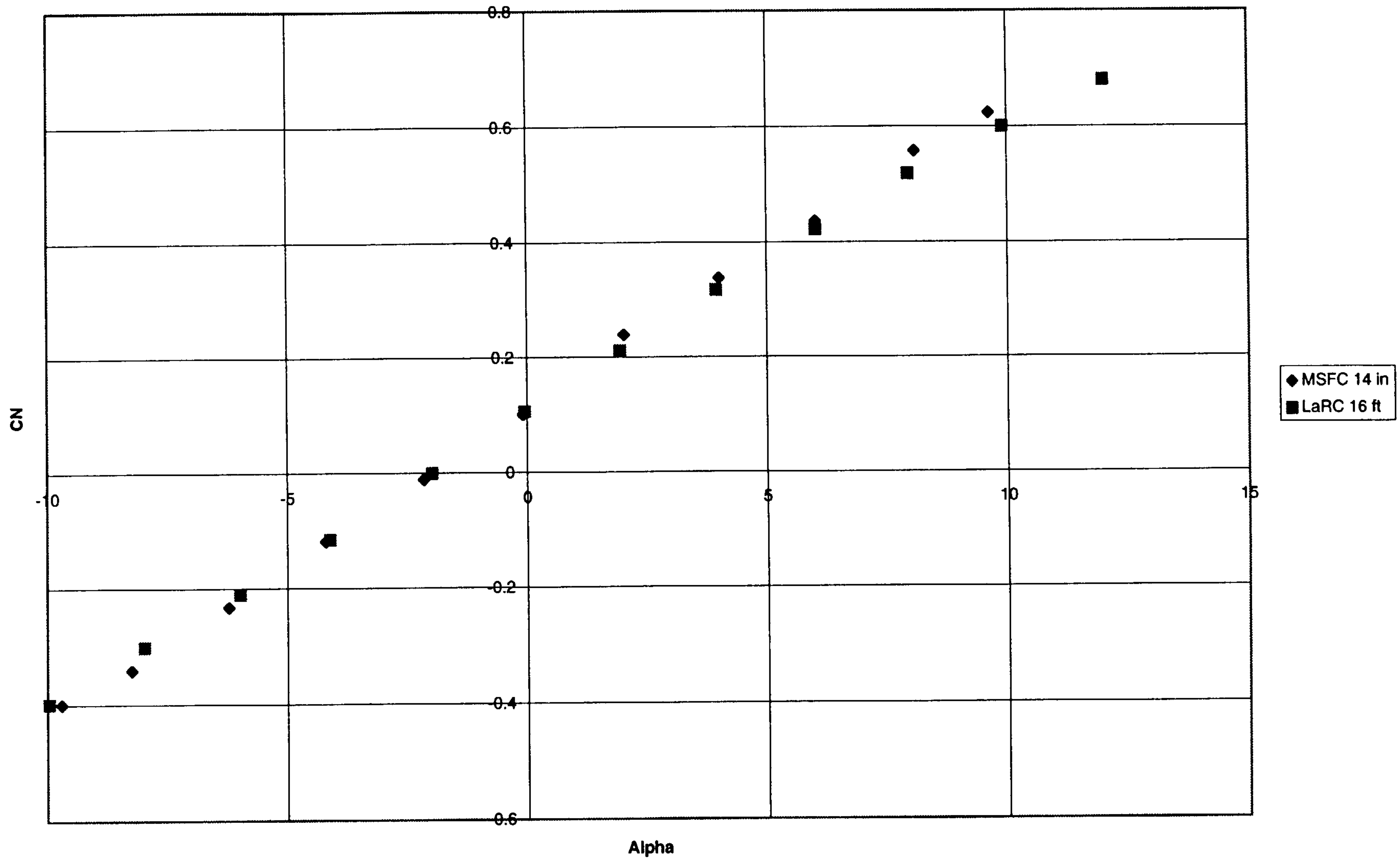


Fig 5

CM M 0.3

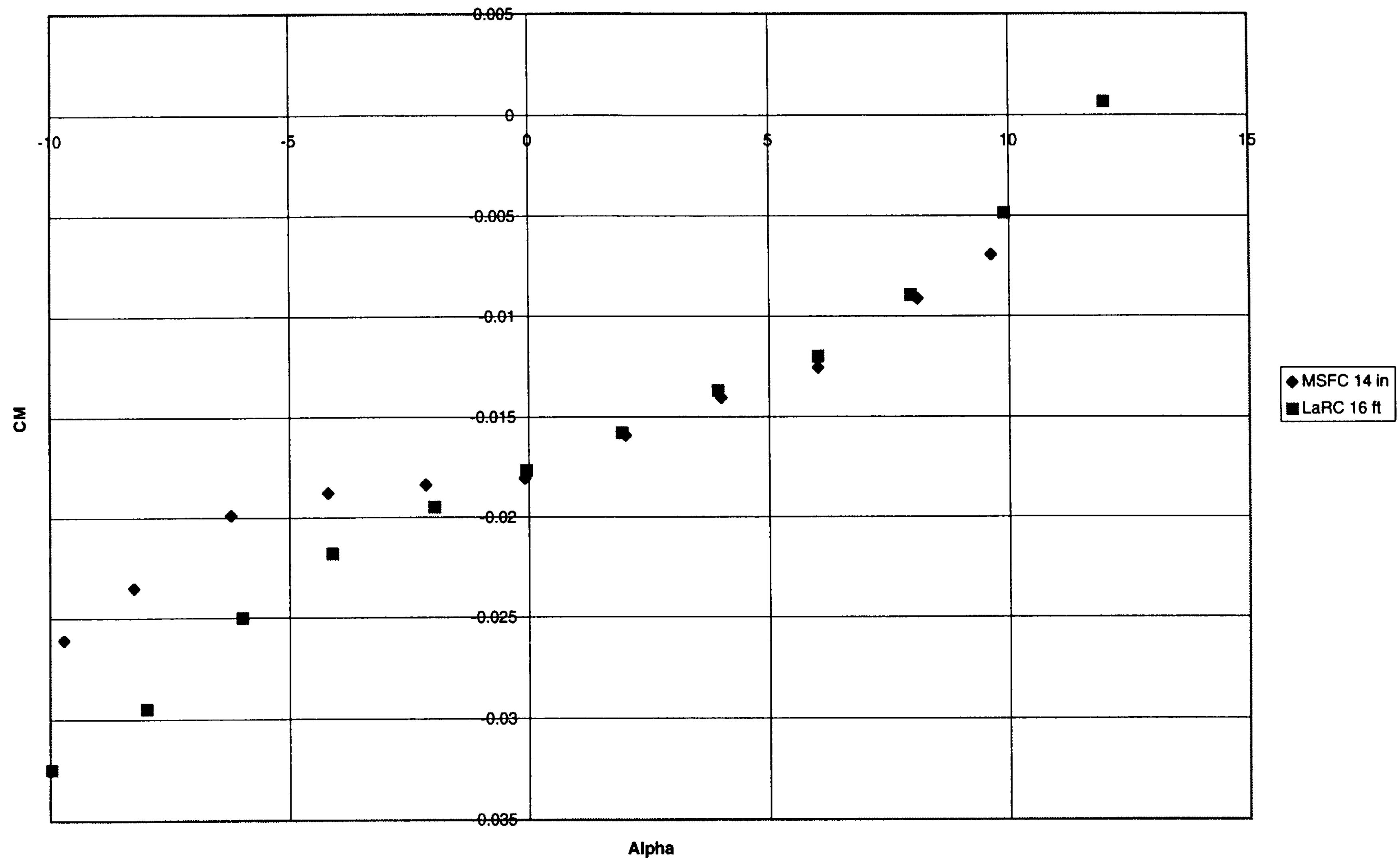
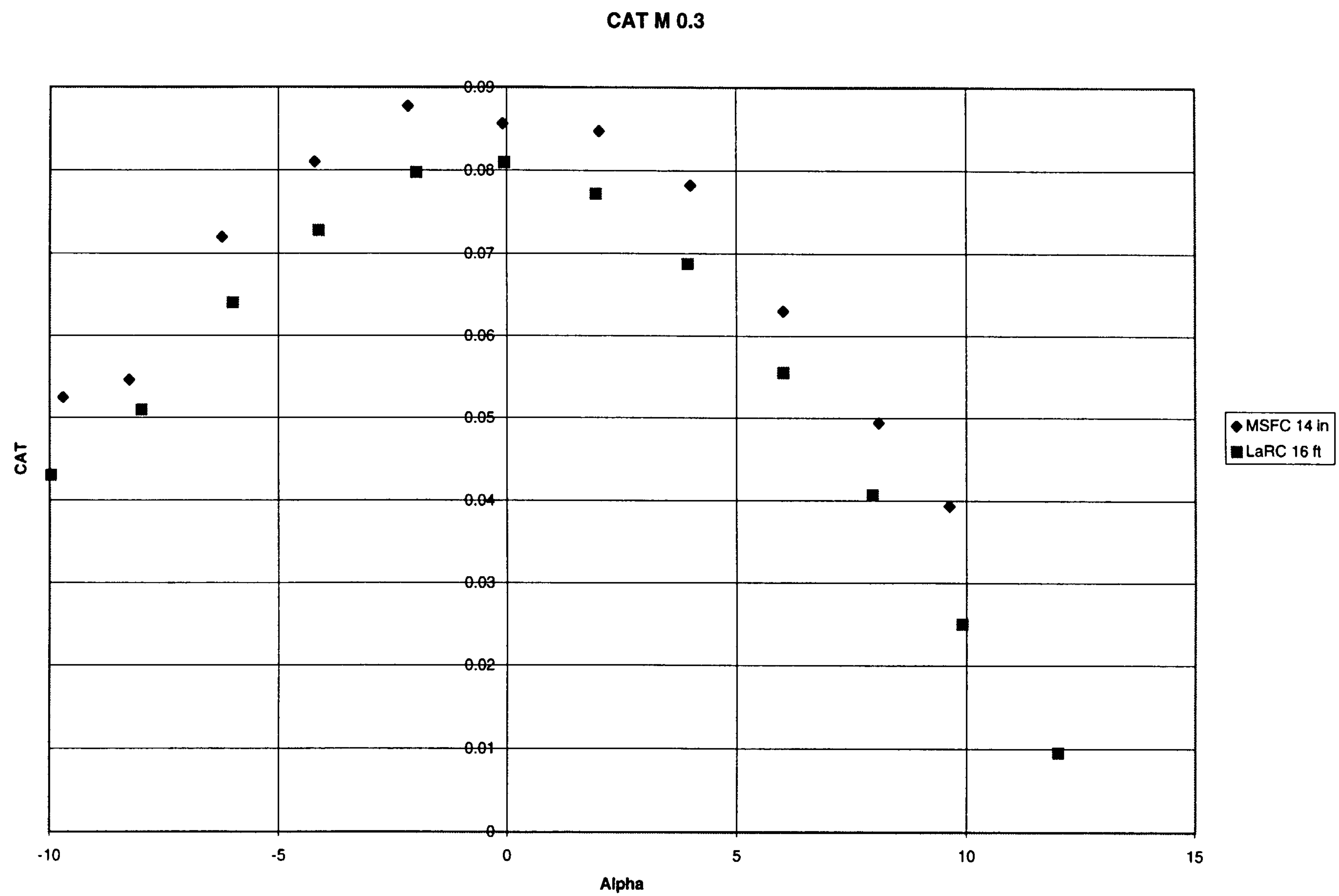

0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-10
-5
0
5
10
15
CM
Alpha
MSFC 14 in
LaRC 16 ft

Fig 6


CAT M 0.3
CAT
Alpha
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
-10
-5
0
5
10
15
MSFC 14 in
LaRC 16 ft

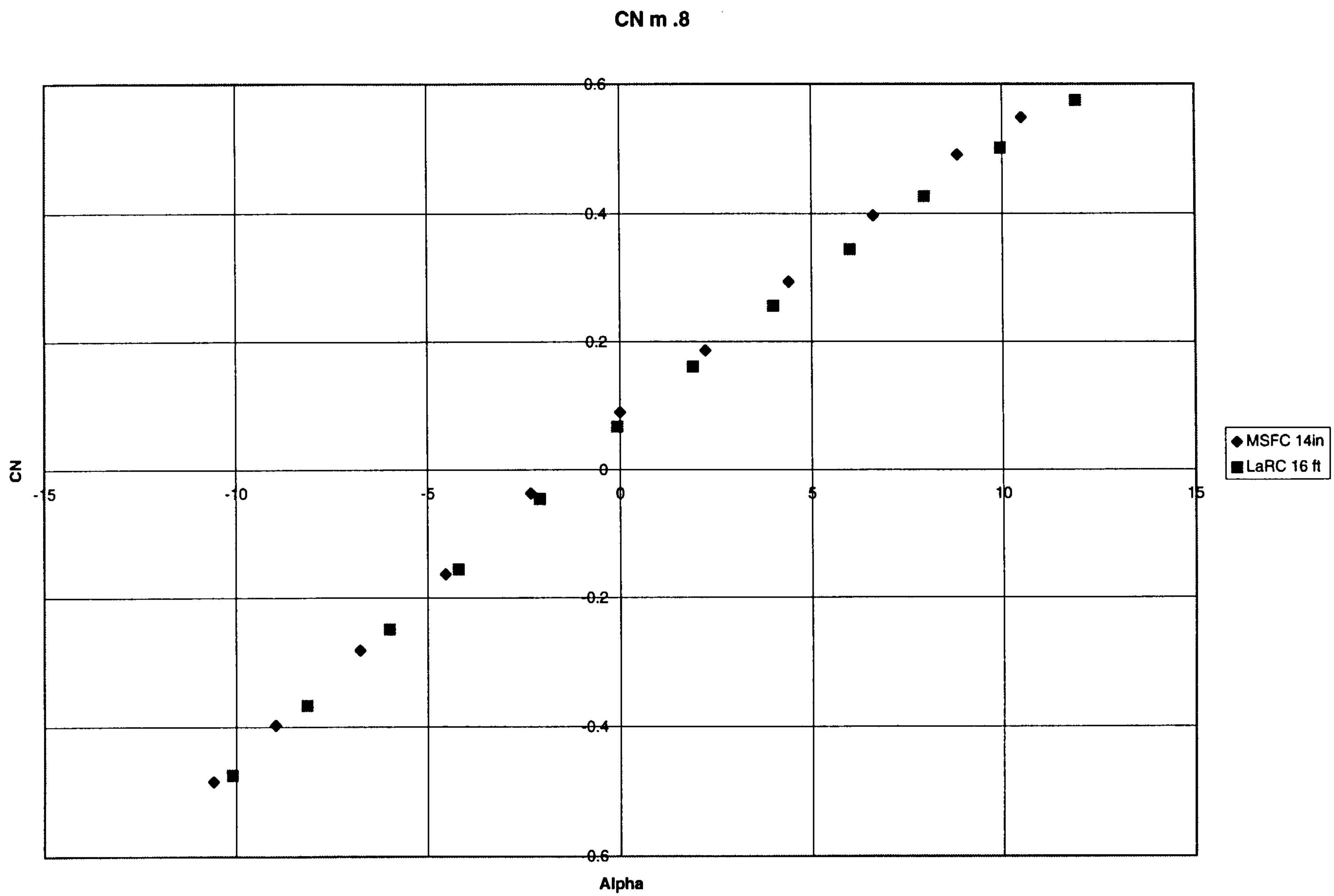
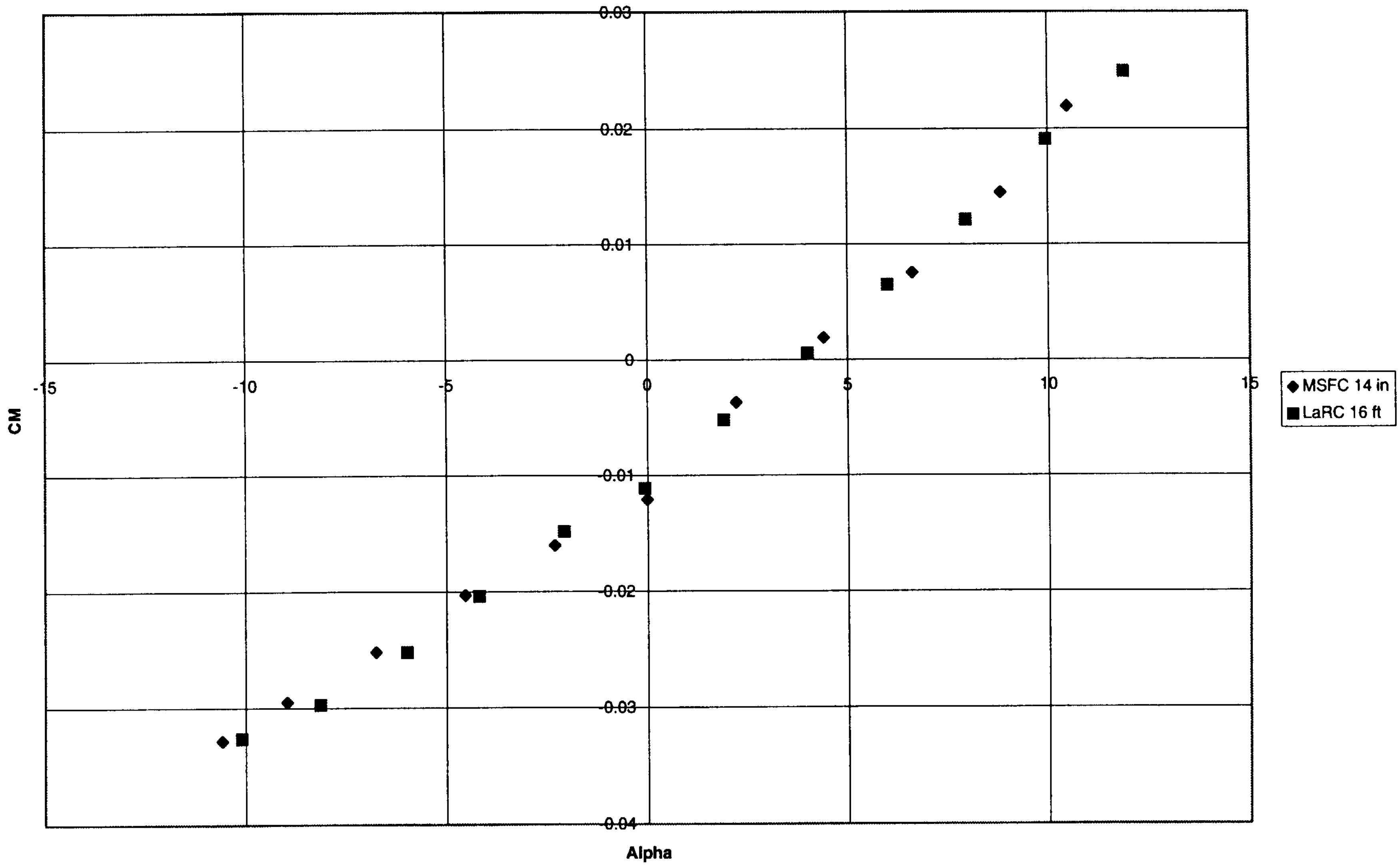

CN m .8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-15
-10
-5
0
5
10
15
CN
Alpha
MSFC 14in
LaRC 16 ft

Fig 8

CM M .8


0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-15
-10
-5
0
5
10
15
CM
Alpha
MSFC 14 in
LaRC 16 ft

CAT M .8

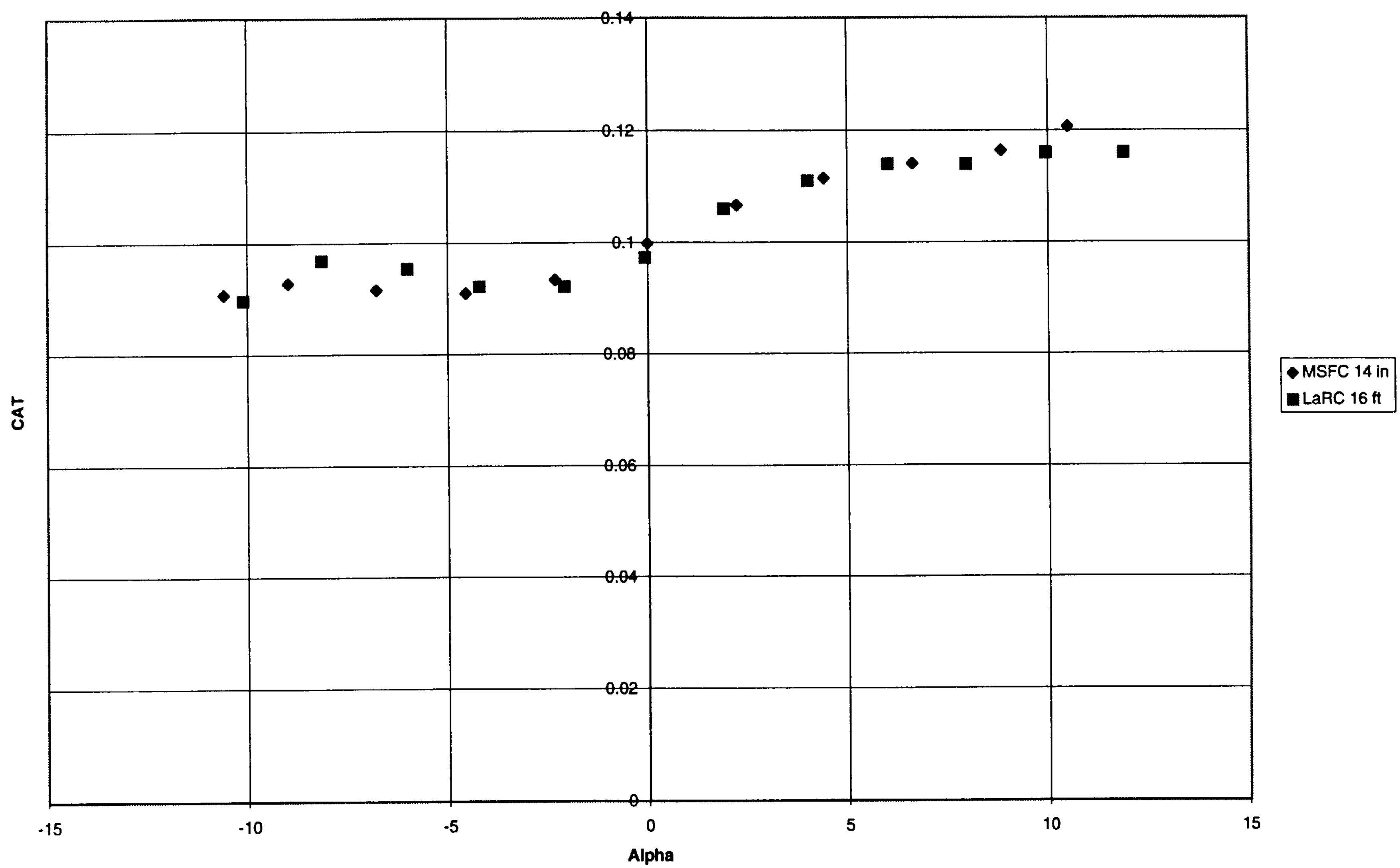

0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-15
-10
-5
0
5
10
15
Alpha
CAT
MSFC 14 in
LaRC 16 ft

Fig 10

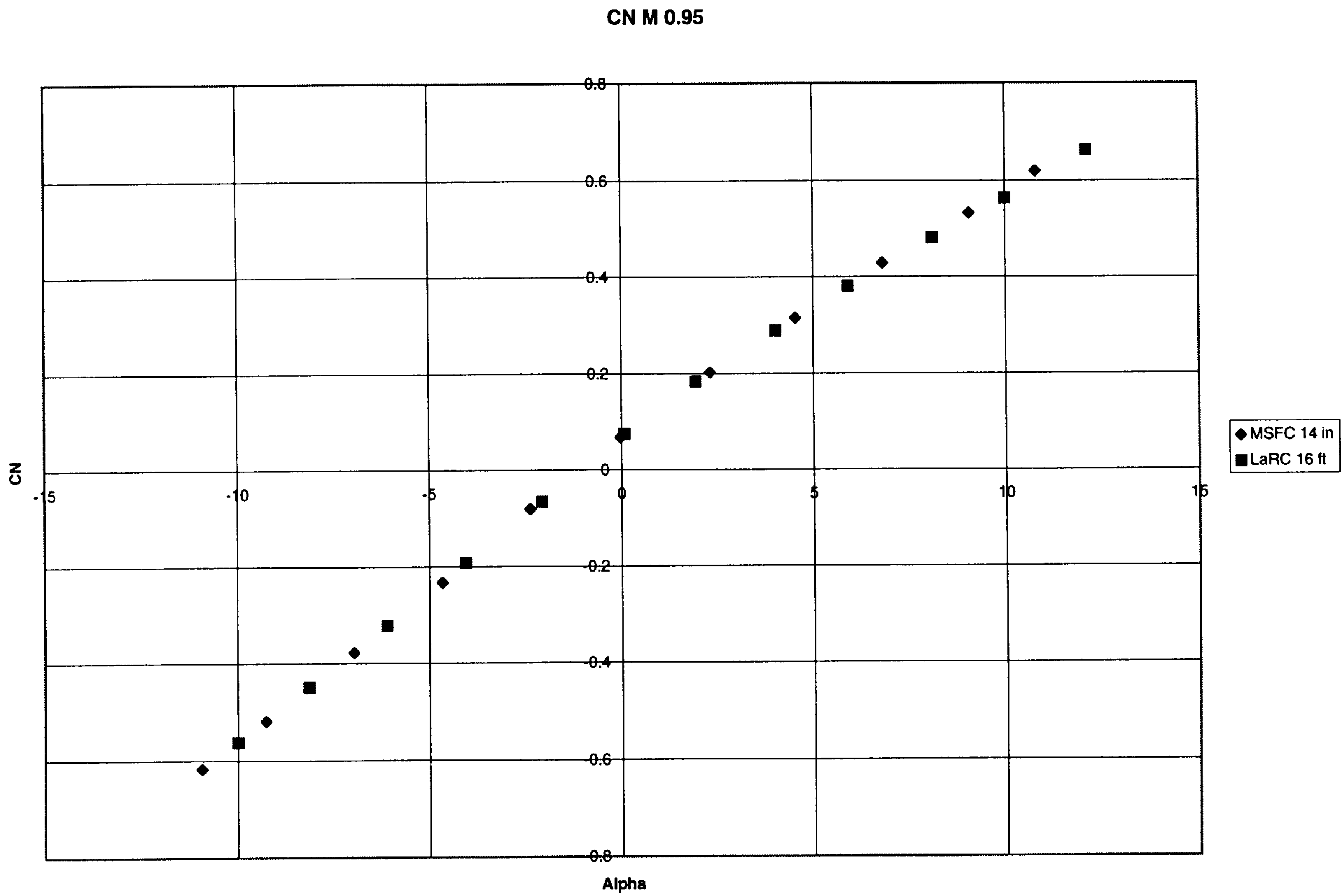
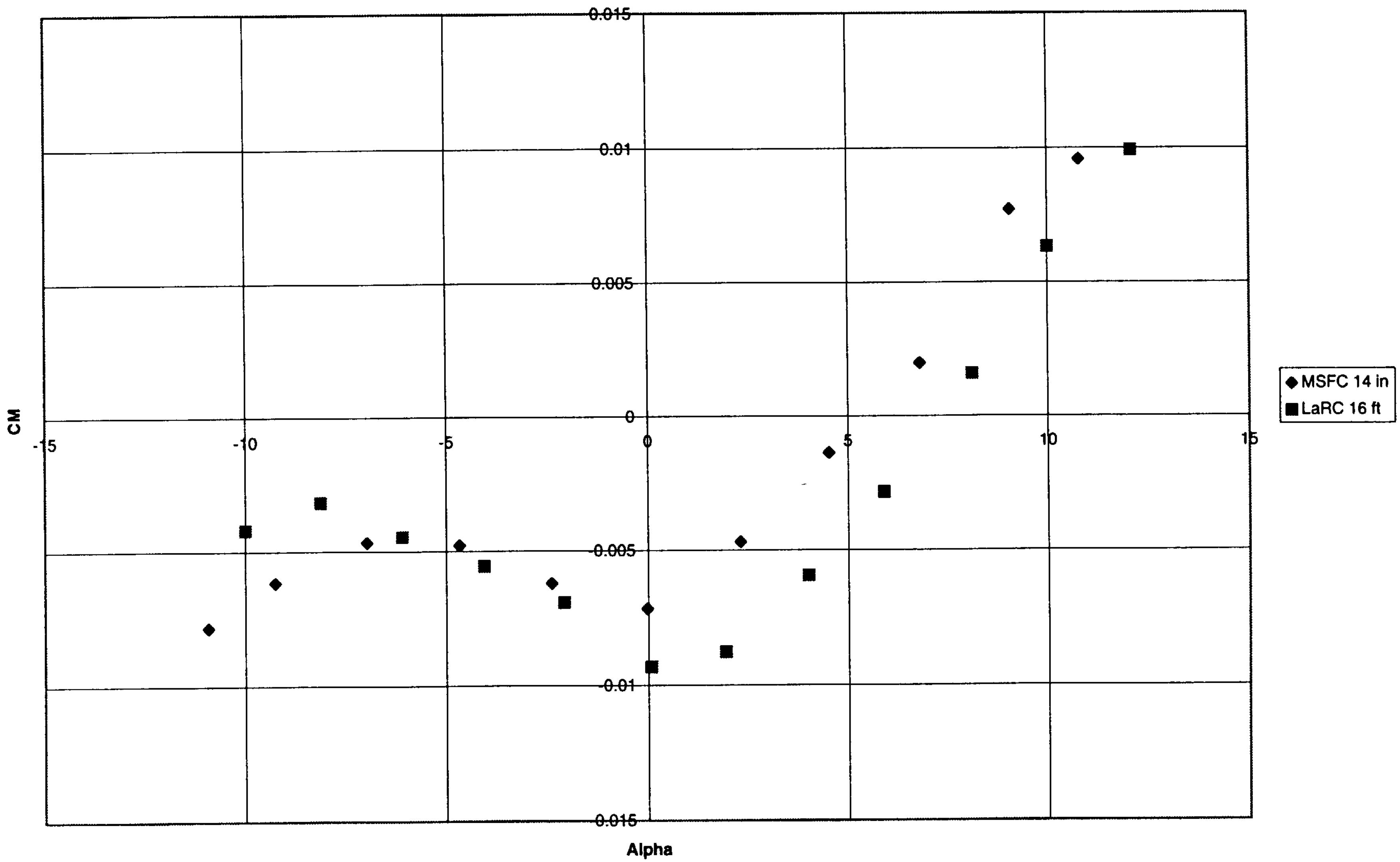

CN M 0.95
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-15
-10
-5
0
5
10
15
CN
Alpha
MSFC 14 in
LaRC 16 ft

Fig 11

CM M 0.95


CM
Alpha
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-15
-10
-5
0
5
10
15
MSFC 14 in
LaRC 16 ft

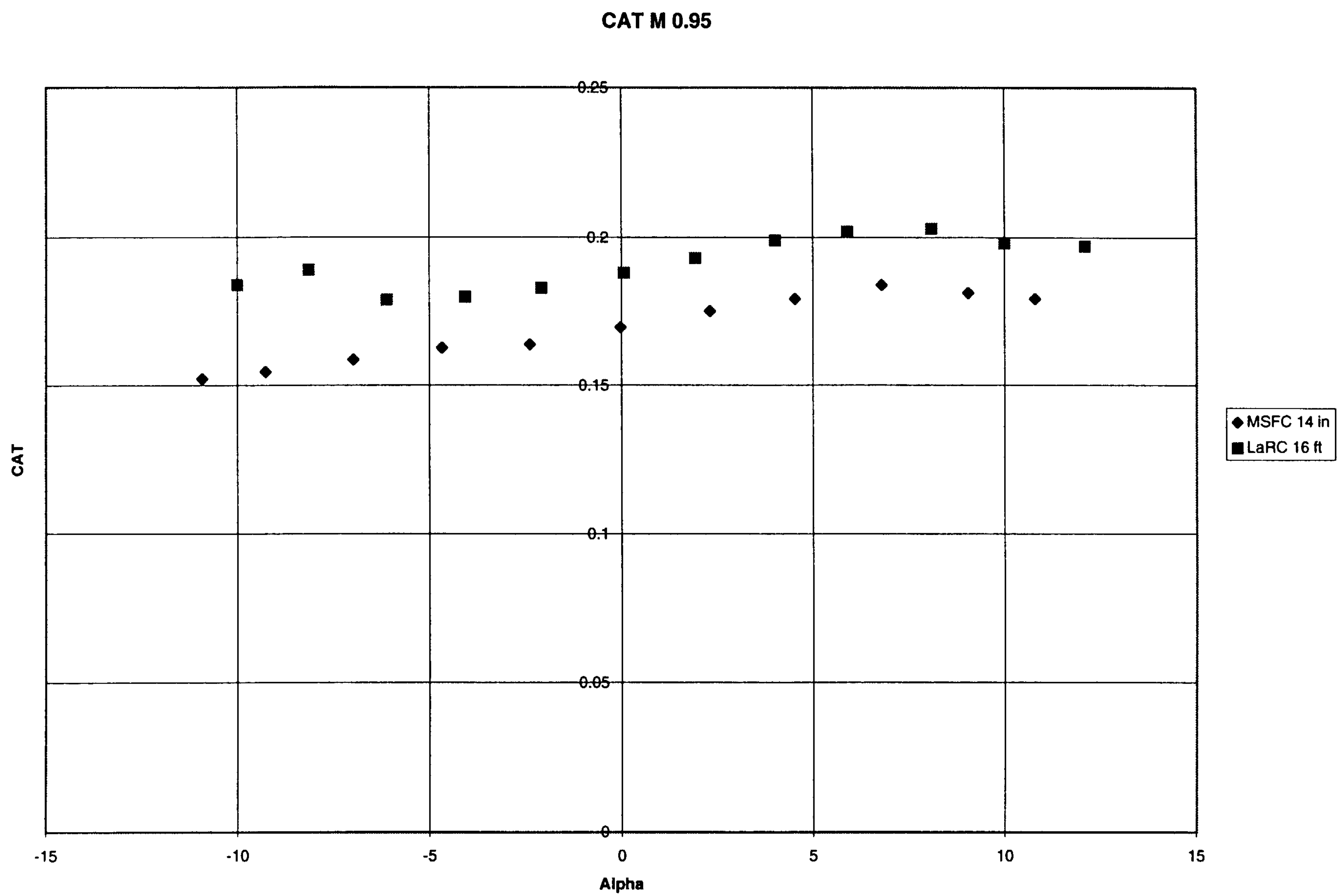
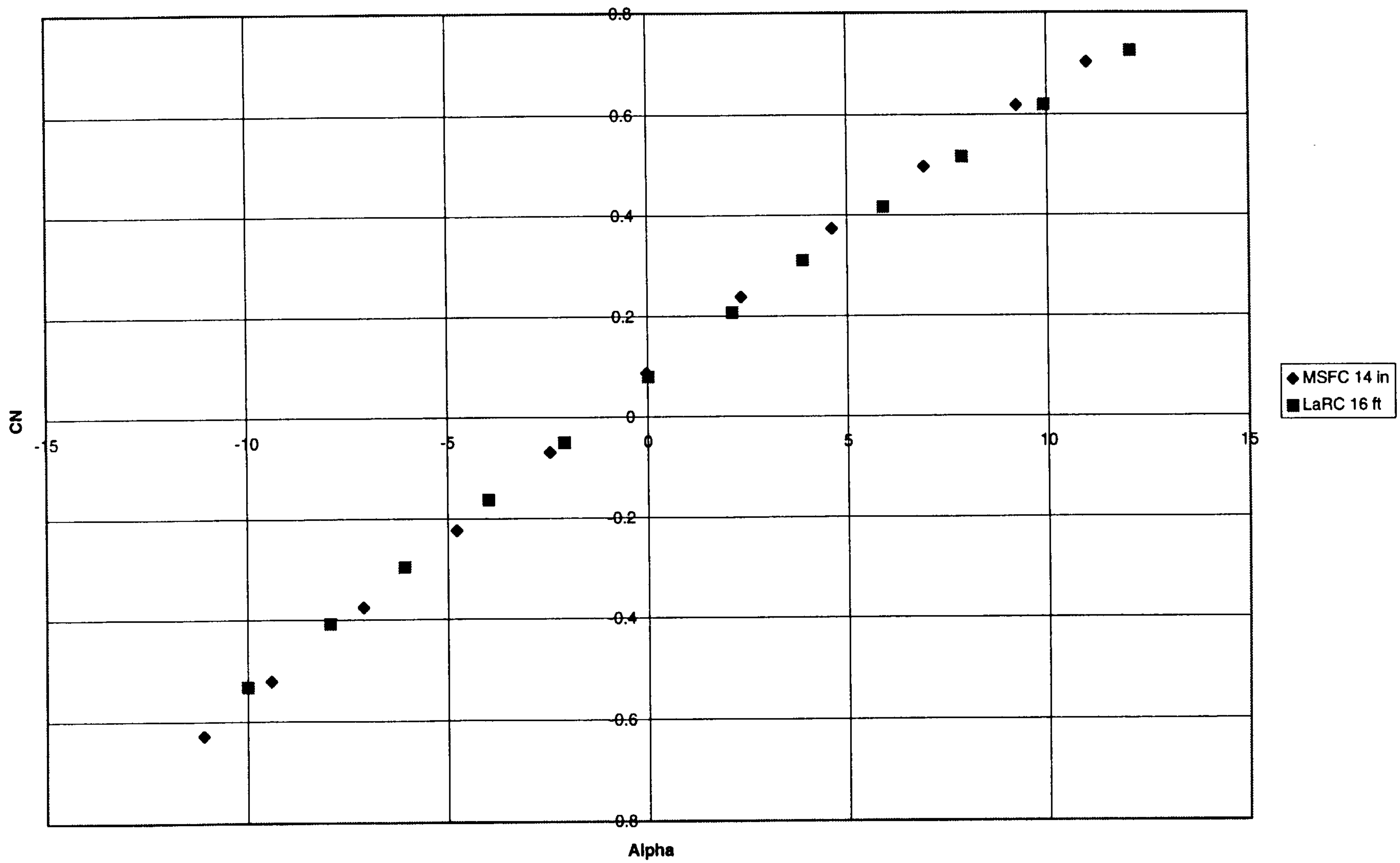

CAT M 0.95
0.25
0.2
0.15
0.1
0.05
0
CAT
-15
-10
-5
0
5
10
15
Alpha
MSFC 14 in
LaRC 16 ft

Fig 13

CN M 1.15


CN
Alpha
-15
-10
-5
0
5
10
15
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
MSFC 14 in
LaRC 16 ft

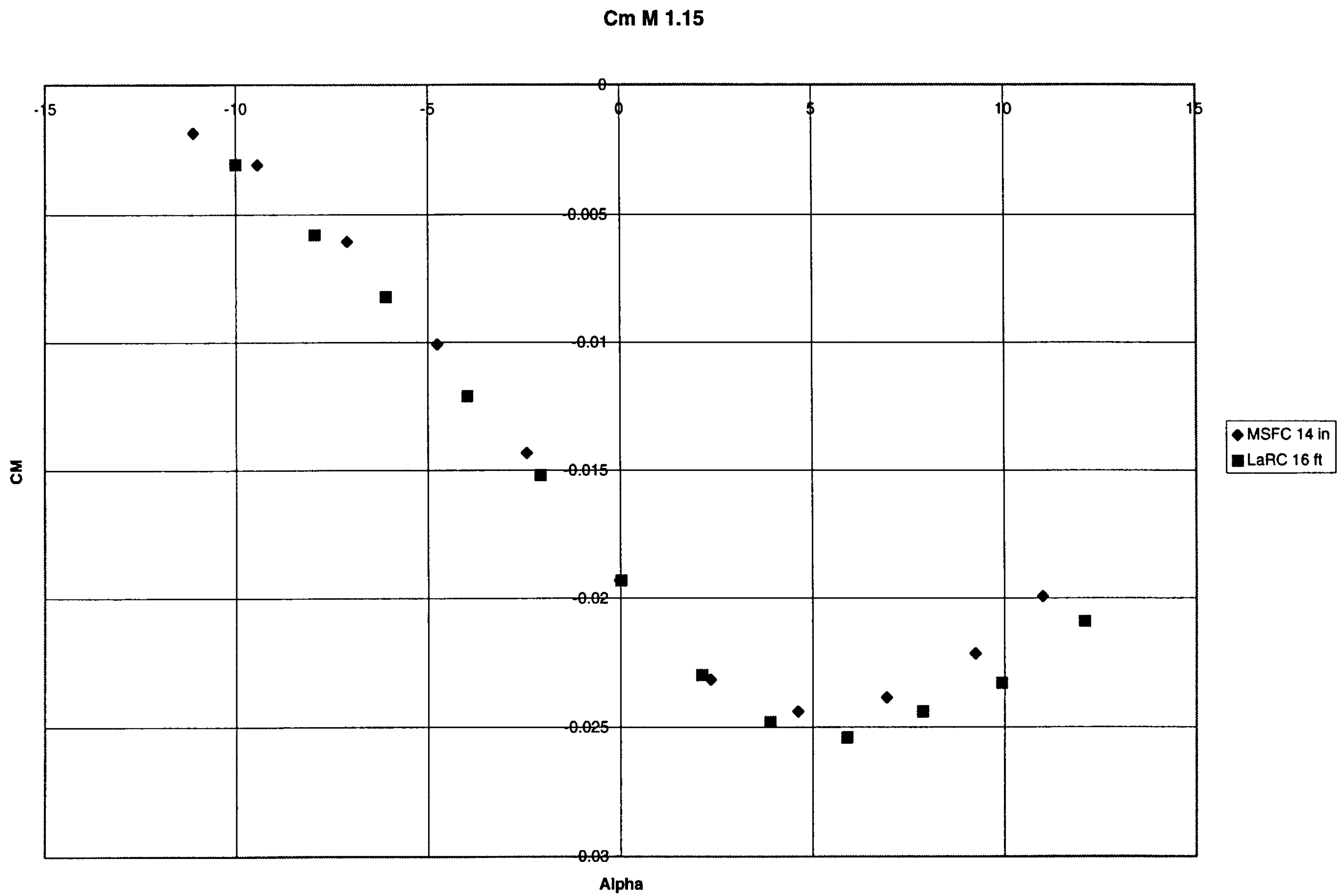

Cm M 1.15
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-15
-10
-5
0
5
10
15
CM
Alpha
MSFC 14 in
LaRC 16 ft

Fig 15

CAT M 1.15

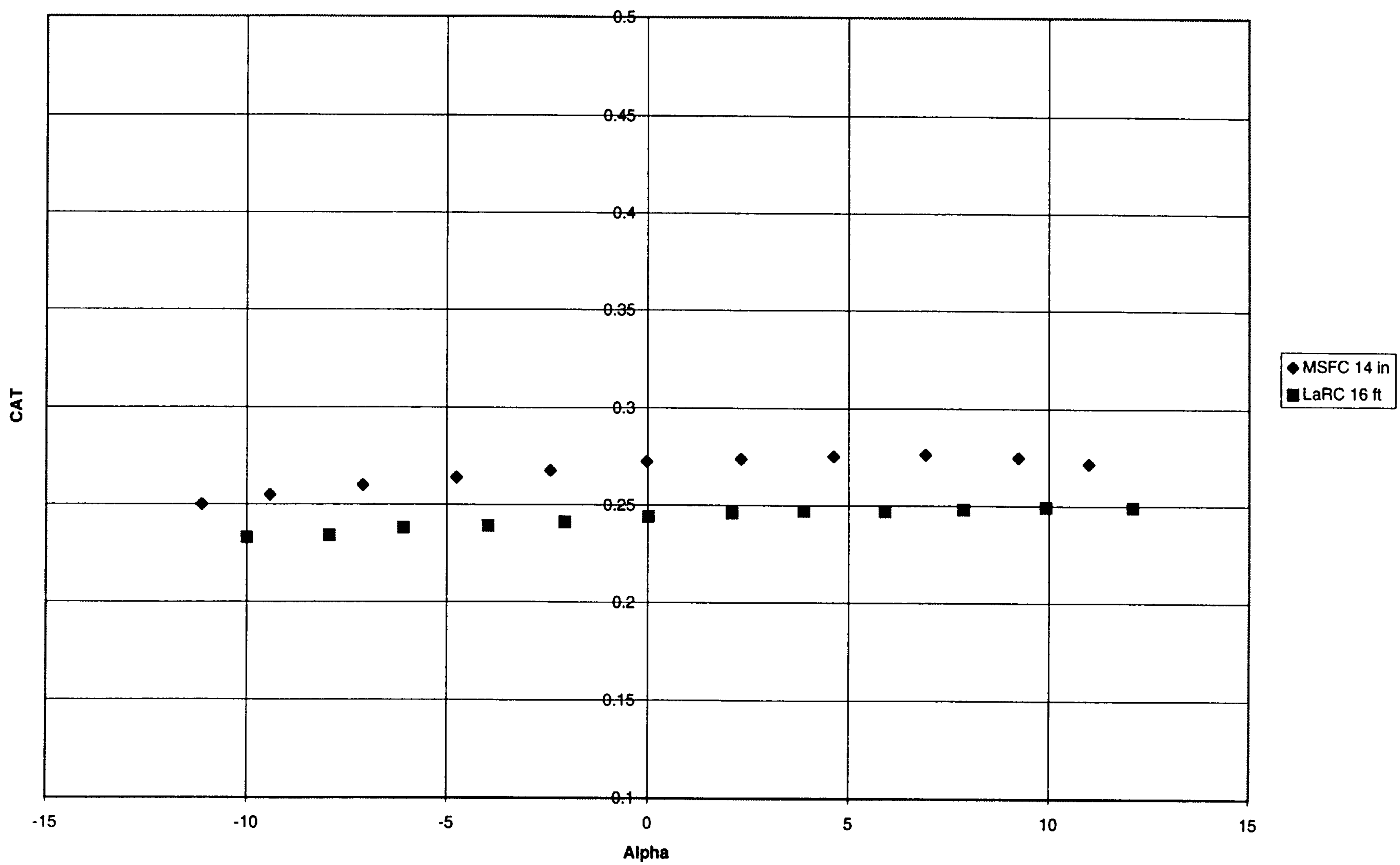


Fig 16

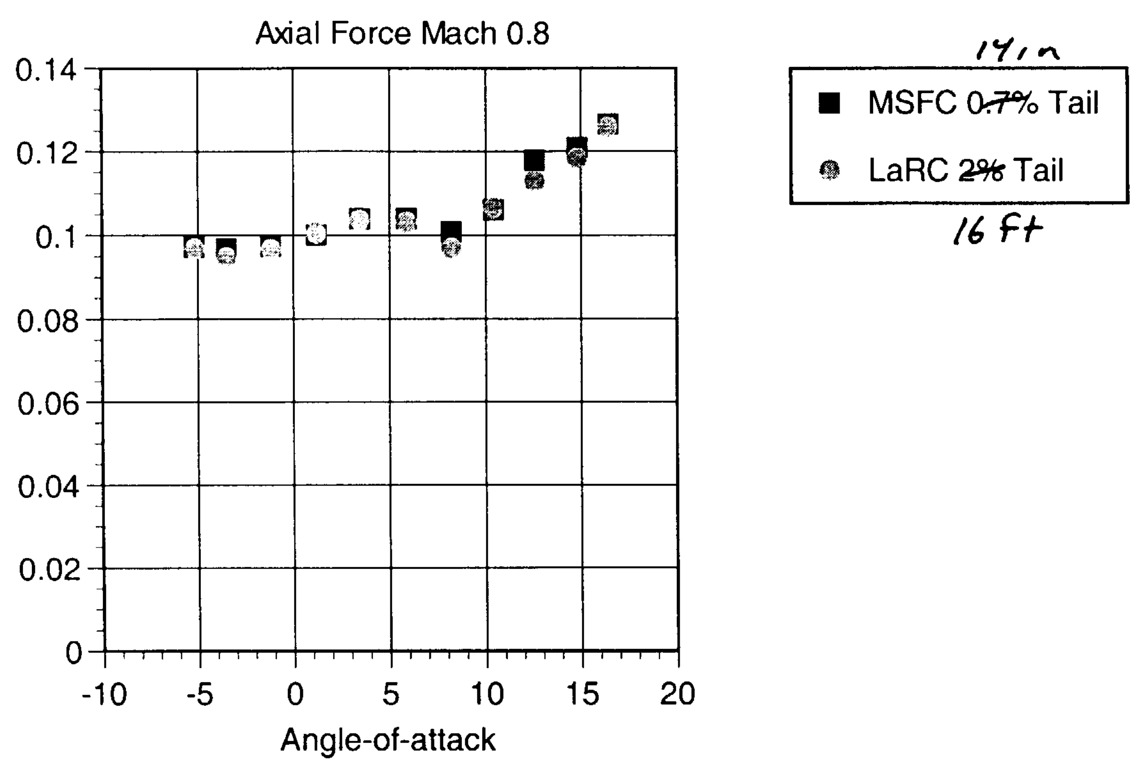

Axial Force Mach 0.8
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-10
-5
0
5
10
15
20
Angle-of-attack
14 in
MSFC ~~0.7%~~ Tail
LaRC ~~2%~~ Tail
16 ft

Fig 17

Pitching Moment Mach 0.8

~~GM 0.8~~

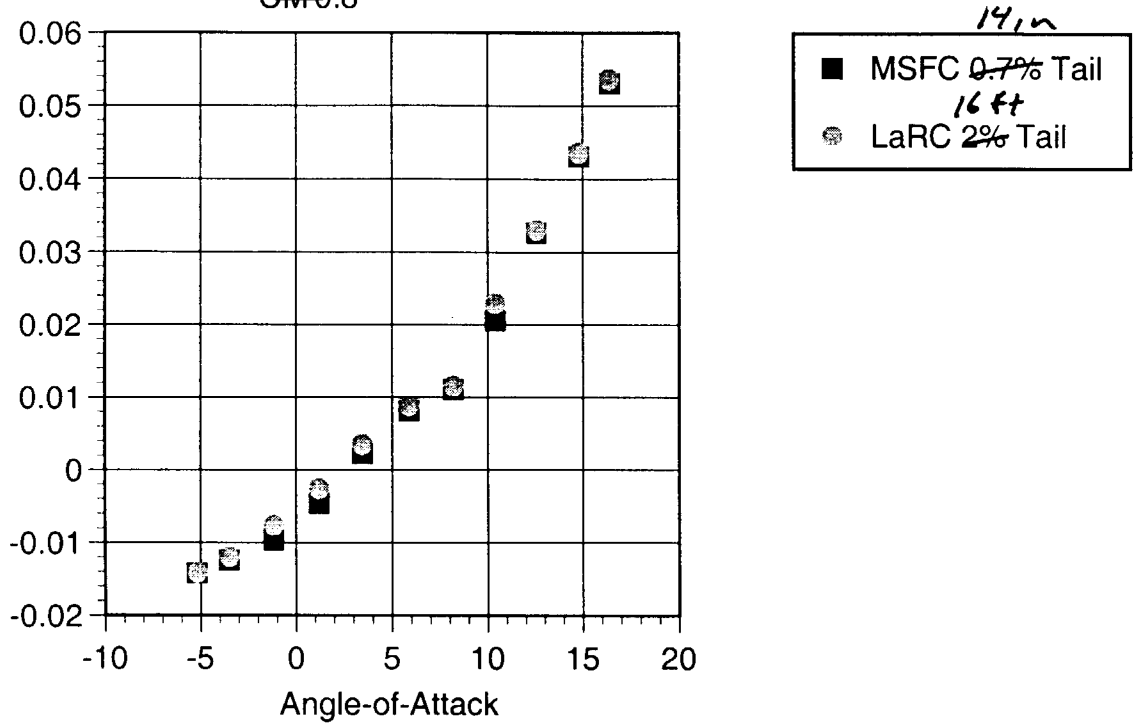


Fig 18