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SUMMARY

Aerodynamic evaluation tests have been made at ambient and at cryogenic temperatures with the latest Langley design of an internal strain-gage balance designed for operation in a cryogenic wind tunnel. A sharp leading-edge 75° delta-wing model was used to provide the aerodynamic loading for these tests. The balance was tested in various configurations that included the use of electrical resistance heaters, insulating and noninsulating adapters between the model and the balance, and a convection shield. The evaluation was made by comparing the data at a tunnel stagnation temperature of 300 K with data taken at 200 K and 110 K while matching either the Reynolds number or the stagnation pressure. The data were obtained over a range of angle of attack up to about 29° and at Mach numbers of 0.3 and 0.5.

The wind tunnel tests show that it is possible to acquire accurate, repeatable force and moment data in a cryogenic wind tunnel while operating at steady-state thermal conditions with this latest design internal strain-gage balance, either with or without electrical resistance heaters being used to control balance temperature. The convection shield was shown to improve the stability of the balance output in both heated and unheated configurations. There were no apparent Reynolds number effects, within the limits of the balance accuracy, on the aerodynamic results for the delta-wing model.

INTRODUCTION

Research into the problems involved in measuring aerodynamic forces and moments on a three-dimensional aircraft model with an internal strain-gage balance in a transonic cryogenic wind tunnel has been underway at the Langley Research Center for several years. (See refs. 1 and 2.) This work has been directed toward the goal of being prepared to perform useful aerodynamic research in the new National Transonic Facility at the Langley Research Center (NTF) when this large transonic cryogenic wind tunnel becomes operational. Internal strain-gage balances have been in wide use in wind tunnels for many years at ambient temperatures and at elevated temperatures. The NTF, however, will require the use of internal strain-gage balances capable of accurately measuring forces and moments at temperatures ranging from 77.4 K (the temperature of liquid nitrogen at ambient pressure) up to about 340 K and at stagnation pressures from ambient up to 890 kPa (8.8 atm). The low temperatures, in particular, impose many new problems on the design, fabrication, and use of strain-gage balances.

The first test of an internal strain-gage balance in a cryogenic wind tunnel was in 1972 in an 18 cm by 28 cm low-speed cryogenic tunnel (refs. 3 and 4). The balance used for these early tests was an existing three-component water-jacketed balance with the designation HN05. For the test in the low-speed cryogenic tunnel, tap water at room temperature was circulated through the water jacket to keep the strain-gage balance from becoming too cold. Some problems were encountered with algae clogging the tubes and preventing water from circulating through the water jacket. This, in turn, allowed the water to freeze and to split the seams of the water jacket. However, in spite of the problems, generally good agreement for data on a sharp leading-edge delta wing was obtained over a temperature range from 322 K to 111 K.

The next tests at Langley with a strain-gage balance in a cryogenic wind tunnel were made in 1974 with a three-component, electrically heated balance (designated HRC-1) which had been developed specifically for use in a cryogenic tunnel. These tests were made in the Langley 0.3-m Transonic Cryogenic Tunnel (TCT), which at that time had a slotted, octagonal test section that measured 0.34 m across the flats. Details of these tests are in reference 1. The HRC-1 balance utilized a combination of resistance heaters, an insulator between the model and the balance, and a similar insulator between the balance and the sting. In addition, a thin cylindrical tube was cantilevered forward over the balance to serve as a "convection shield." This convection shield keeps the circulating cold gas stream within the balance from impinging directly on the active balance elements. Comparative tests with ambient temperature data were made with the balance heated and unheated at cryogenic temperatures. As noted in reference 1, some problems were encountered with thermal control and temperature gradients. It was concluded, however, that keeping the balance heated to ambient temperature during tests at cryogenic temperatures appeared to be a sound approach. Also, it was suggested in reference 1, ... "the concept of allowing balance temperature to vary with stagnation temperature should be investigated further since the absence of heaters and insulators on the balance would make possible a reduction in balance diameter for a given load capacity."

Since the inception of the cryogenic wind tunnel concept in 1971, development work has also taken place at other research centers on the use of strain-gage balances at cryogenic temperatures. The use of existing strain-gage balances with the addition of heaters in a blowdown type of cryogenic wind tunnel with relatively short run times is discussed in references 5 and 6. Ongoing work on both heated and unheated strain-gage balances in several countries in Europe is summarized in reference 7.

The purpose of this paper is to present the aerodynamic results of the third series of tests at Langley of a strain-gage balance in a cryogenic wind tunnel. These tests utilized the latest evaluation balance, the HRC-2. In the years between the design of the HRC-1 and the HRC-2, personnel of the Langley Instrument Research Division were involved in a comprehensive balance development and evaluation effort with research done on balance construction, strain gages, adhesives, solder, wires, and moistureproofing. Details of this effort have been reported in references 2, 8, and 9. The entire development program was aimed at minimizing the effects of cryogenic temperatures on strain-gage balance output.

The results presented in this paper were obtained from two separate wind tunnel entries, with additional testing, evaluation, and improvements to the strain-gage balance taking place between the first entry and the second entry. The first entry in the 0.3-m TCT with the HRC-2 balance occurred in 1979 and the second entry in 1981. A sharp leading-edge delta-wing model was used to load the balance aerodynamically, since such a configuration should be relatively insensitive to any changes in test Reynolds number resulting from changes in operating pressure or temperature. The objective of these tests was to determine the performance of the HRC-2 balance under actual cryogenic wind tunnel test conditions. The method used was to compare force and moment data taken at a typical tunnel stagnation temperature of 300 K with data taken at stagnation temperatures of 200 K and 110 K. In the first entry, the balance could be used at cryogenic temperatures either with electrical heaters operating to maintain the balance temperature at 300 K or with the electrical heaters not operating to allow the balance temperature to vary with tunnel stagnation temperature. In addition, the use of a convection shield on the balance and an insulating adapter between the model and the balance were investigated. The electrical resistance heaters and the insulating adapter were not used during the second tunnel entry. These tests were made at Mach numbers of 0.3 and 0.5 and at angles of attack from -6° to 29°. The tunnel stagnation pressure was varied from 122 kPa (1.2 atm) to 491 kPa (4.8 atm) in order to compare results at constant Reynolds number with different values of tunnel stagnation temperature. The pressure was also varied at a constant tunnel temperature to determine model sensitivity to changes in Reynolds number. All the results presented in this report are steady-state results, in that sufficient time was allowed for the balance temperatures, as monitored by thermocouples, to reach equilibrium values.

SYMBOLS

The aerodynamic data presented in this report are referred to the body system of axes. The origin for these axes is the moment reference center located at 25 percent of the mean geometric chord. Model dimensions given below are those with the model at a temperature of 294 K.

$\bar{c}$ mean geometric chord, 2/3 c_{root}, 0.1580 m

c_{root} model root chord, 0.2370 m

C_A axial-force coefficient, $\frac{\text{Axial force}}{qS}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$

C_N normal-force coefficient, $\frac{\text{Normal force}}{qS}$

M free-stream Mach number

p_t stagnation pressure, Pa or atm

q free-stream dynamic pressure, Pa

R Reynolds number based on $\bar{c}$

S wing planform area, 0.01504 m^2

T_t stagnation temperature, K

α angle of attack, deg

APPARATUS AND PROCEDURE

Wind Tunnel

The Langley 0.3-m Transonic Cryogenic Tunnel (TCT) is a single return, fan-driven wind tunnel which utilizes nitrogen as the test gas. The two-dimensional test section (fig. 1) presently installed in the tunnel circuit is 20.3 cm wide and 61.0 cm high. For this investigation, the test section had a slotted floor and ceiling and solid sidewalls. The traversing wake-survey probe, shown in figure 1, was removed for these tests. A motor-driven turntable, 22.8 cm in diameter, is centrally located in each sidewall for the mounting of two-dimensional airfoil models. The Mach number capability of the 0.3-m TCT with the two-dimensional test section is from about 0.05 to 0.95. Stagnation pressure can be varied from about 122 kPa (1.2 atm) to about 608 kPa (6.0 atm) and the stagnation temperature range is from about 77 K to 327 K. Additional information on the cryogenic-tunnel concept and on the operating characteristics of the 0.3-m TCT is contained in references 3, 10, 11, and 12.

Model

The model chosen to provide the aerodynamic loading for the balance evaluation is a sharp leading-edge 75° delta wing as shown in figure 2. One advantage of using a sharp leading-edge delta-wing model for this purpose is that such a configuration is considered to be relatively insensitive to changes in test Reynolds number. The thick diamond-shape cross section in the spanwise direction was used in order to prevent any aeroelastic distortion of the model from affecting the aerodynamic results. This model is similar to the delta-wing model of reference 1, which was selected for the same reasons. The balance was located with respect to the model center of pressure such that full-scale normal force on the balance resulted in near full-scale pitching moment being applied to the balance. No artificial roughness was applied to the model to trip the boundary layer during these tests.

The model itself was machined from a single piece of A-286 steel. Adapters of two different materials were used between the balance and the model. One was made of glass-cloth reinforced epoxy to provide a relatively good thermal insulator between the balance and the model when the balance heaters were being used. The other adapter was made of steel to provide a metal-to-metal interface between balance and model. A single expansion-type steel dowel pin was used to locate properly the balance, adapter, and model with respect to one another. Some difficulty was encountered in maintaining a close fit of the insulating adapter with both the model and with the balance, since the fit of the insulating adapter changed with variations in humidity and temperature.

Model Support System

A strut with a circular arc airfoil section was attached to the turntable on each side of the tunnel test section. The strut supported a short sting on which the balance and model were mounted. This arrangement is shown in figure 3, and a photograph of the model, sting, and support strut is shown in figure 4. The motor-driven turntables provide the angular rotation in pitch for the model. The sting was made from VascoMax C-200 maraging steel and the airfoil strut was made of A-286 steel. The turntables were made from 7075-T6 aluminum alloy.

Balance

The balance used for these tests is a one-piece, internal strain-gage balance. It was designed specifically for evaluation and was fabricated and gaged for cryogenic use. This balance, designated HRC-2, is shown in figure 5. It is a three-component balance (normal, axial, and pitch) that is 2.54 cm in diameter and 21.21 cm long and is suitable for use in the TCT. It is made of VascoMax C-200 maraging steel and has Micro-Measurements K-alloy strain gages. In addition, HRC-2 has thermofoil resistance heaters for thermal control and type T (copper-constantan) thermocouples for temperature readout.

Since temperature gradients are most likely to occur along the length of a balance, it is desirable to have all four active arms of a strain gage bridge at one station on the balance. A balance wired in this manner is called a "moment" balance and results in the electrical outputs of the forward and aft bridges having to be summed to obtain an output proportional to the applied pitching moment and differenced to obtain an output proportional to the applied normal force. HRC-2 was wired in this manner to minimize gradient effects and to simplify temperature compensation and data reduction.

This three-component balance has the following full-scale design loads:

Normal force - 890 newtons
Axial force - 222 newtons
Pitching moment - 28.2 newton-meters

The accuracy of this strain-gage balance is given as ±0.5 percent of the full-scale design loads. The accuracy may be expressed in terms of each of the aerodynamic coefficients and is then dependent on the particular model reference dimensions and on the dynamic pressure of the particular test. For these tests, the quoted accuracy of ±0.5 percent for the HRC-2 balance, with the dynamic pressure in pascals and the room temperature dimensions of the model used, may be given as

$$\Delta C_N = \pm \frac{296}{q}$$

$$\Delta C_A = \pm \frac{73.9}{q}$$

$$\Delta C_m = \pm \frac{59.4}{q}$$

The model, balance, model-to-balance adapters, convection shield, and sting are shown in figure 6. The tubular convection shield, made from glass-cloth reinforced epoxy, is attached to the sting end of the balance and cantilevered forward over the gage section of the balance. The shield is used to minimize heat loss from the balance and also to improve the stability of the balance output signals, as discussed in reference 8. The insulating adapter and the steel adapter are interchangeable parts which fit between the balance and the model.

The following table summarizes the configuration numbers as used in the graphical data figures to specify (a) the type of balance adapter between the balance and the model, either the insulating balance adapter or the steel adapter, and (b) the use of the convection shield:

Configuration	Insulating balance adapter	Convection shield
1	On	On
2	Off	On
3	Off	Off

Additional details on this balance may be found in references 2, 8, and 9.

Test Procedures and Data Corrections

All the data presented herein are steady-state results in that the balance temperatures as monitored by thermocouples on the balance were allowed to stabilize before taking data. For those runs in which the balance was heated, the set-point temperature of each heater had to be manually adjusted during the run to achieve the desired temperature of 300 K on the balance at the gage location. This was necessary since the automatic temperature controller did not fully compensate for the changing thermal conditions because of the relative locations of heaters, temperature sensor for the controller, and thermocouples on the balance. The variation of the balance strain-gage output sensitivities with temperature could be predicted from bench tests of the balance in a cryogenic chamber. (See ref. 8.) The equations to correct the balance sensitivities with temperature were incorporated in the data reduction procedure. However, the variation in the balance wind-off zeros with changes in temperature was not repeatable within desired limits, making it necessary to reduce all the data obtained at stagnation temperatures lower than 300 K using beginning-of-run "cold" wind-off balance zeros. These cold zeros were obtained by lowering tunnel stagnation temperature to the desired value with the tunnel running, waiting for the balance temperatures to stabilize, and then quickly stopping the tunnel fan to measure the wind-off balance zeros from the three components.

The procedure followed to record the wind-on data was to start with the model at 0° angle of attack and increase the model attitude in 2° increments up to the maximum as limited either by the allowable balance loads or by the angle-of-attack drive mechanism. Then the model attitude was lowered to -2° and decreased in 2° increments to either -4° or -6° followed by a second 0° angle-of-attack data point. Data were acquired as single-frame filtered data. The attitude accelerometer was located on the plenum side of one of the turntables. This arrangement required a correction for sting and balance deflection under load to be made in the data reduction process in order to compute the model angle of attack.

The model geometric dimensions used to nondimensionalize the aerodynamic coefficients were corrected for thermal contraction effects resulting from the changes in temperature. As pointed out in reference 1, these corrections can lead to differences of about 0.4 percent in C_N and C_A and 0.6 percent in C_m for data on a steel model at a temperature of 110 K when compared with the values obtained using the dimensions determined at room temperature.

The axial-force data have been corrected for model cavity pressure in that test section static pressure has been considered to act over the projected area of the balance cavity in the vertical plane normal to the model axis of symmetry.

The various test points at a Mach number of 0.5 are indicated in figure 7 for the different combinations of tunnel stagnation pressure and temperature.

DISCUSSION OF RESULTS

General Comments

The two wind tunnel entries covered by this report differed in two important respects. For the first entry, no decision had been made as to whether the balance would produce more reliable data operating with the temperature maintained at 300 K on the balance or operating at ambient tunnel conditions. Prior to the first entry tests, laboratory research had indicated that the strain gages behaved predictably at cryogenic temperatures, but temperature-induced outputs had not been minimized. The knowledge gained from the first entry tests and the new gaging techniques developed in the interval between the two entries resulted in the HRC-2 balance being regaged for the second series of tests. The regaged balance has more stable gage outputs, requires smaller temperature corrections, and is designed to operate at cryogenic temperatures without thermal control.

First Wind Tunnel Entry

The results in figures 8 through 16 at a Mach number of 0.5 are from the initial series of wind tunnel tests conducted during July 1979 with the HRC-2 balance. The primary objective was to test the balance, which incorporated the latest design techniques, fabrication processes, and materials, in a cryogenic tunnel. A further objective of these tests was to determine the advantages and disadvantages of the use of electrical resistance heaters on this latest design for a strain-gage balance during an actual test in a cryogenic wind tunnel. Bench tests of the HRC-2 balance previously had been performed in a cryogenic chamber. However, a series of wind tunnel tests in a more realistic environment should provide a better insight into balance performance, while measuring actual aerodynamic data.

Figure 8 compares the results measured on configuration 1 at a stagnation temperature of 300 K with the results at stagnation temperatures of 200 K and 110 K. Tunnel conditions were adjusted to provide the same Reynolds number for all these data. Configuration 1 had both the insulating adapter between the balance and the model and the convection shield installed on the balance. The agreement of the data for the different temperatures and pressures is considered to be very good. The results in figure 8(a), in which the balance heaters were on for stagnation temperatures below 300 K, are essentially the same as those in figure 8(b), in which the heaters were off. In figure 8(b), there is a small offset apparent in axial force between the data points for 110 K at positive and at negative angles of attack, as indicated by the fairing of the data points. This offset is discussed more fully in a later paragraph. The symmetrical model used for these tests shows that there is little or no flow angularity in the test section of the 0.3-m TCT, since the pitching-moment data and normal-force data pass through the origin of the axes. The balance accuracies of ± 0.5 percent of the full-scale loads in terms of the nondimensionalized coefficients are shown as bands along the right-hand edge of the plot in figure 8(a). The accuracy bands for the pitching-moment and normal-force coefficients are much smaller than those of the axial-force coefficients. One reason for this is the choice of scales used on the plot. Another reason is that the axial-force component was loaded to only about 22 percent of its design load with the particular model used for this test, even at the highest total pressure. In contrast, the other two components were loaded to nearly full-scale design load.

Figure 9 is a comparison of results at 300 K for two different values of the stagnation pressure. This gives a variation in Reynolds number from 1.88×10^6 to 7.60×10^6. These data are in good agreement when considering the quoted balance accuracies. Thus, as expected, the vortex-type flow on this sharp leading-edge, highly swept delta-wing model is apparently not sensitive to changes in Reynolds number over the range in figure 9.

The results of testing at 110 K with the balance heaters off and on are compared with ambient temperature data at the same stagnation pressure in figure 10. The

Reynolds number range is the same as in figure 9. Good agreement for these data is shown over the complete angle-of-attack range from about -6° to about 27° except for the same offset in axial force mentioned for figure 8(b).

The results for configuration 2, with the insulating adapter between the model and the balance replaced by the steel adapter, are contained in figures 11 through 14. The data in figure 11(a) with the balance heaters on are very similar to those in figure 8(a). However, in figure 11(b), the axial-force coefficients at 110 K with the balance heaters off are lower for angles of attack from -6° to 0° and for the repeat points of 2° and 12° than are the data at 200 K or 300 K and those of figure 8. During cryogenic testing in the lab, it was noted that a "step" zero shift would sometimes occur in the axial output at cold temperatures. This zero shift was not predictable and no explanation was found for it, but it was thought to be caused by the moistureproofing compound applied to the exposed wiring on the balance. This type of zero shift is apparent in some of the data taken during the first tunnel entry and presented later. If the aforementioned data points are shifted upward by the magnitude of this apparent zero shift, the data agree quite well. The zero shift in figure 11(b) was noted during the test, and a repeat run was made as represented by the square symbols in figure 12. No zero shift occurred during the repeat run.

Figure 13 is a comparison at 300 K for two values of stagnation pressure for configuration 2. The figure shows, as did figure 9 for configuration 1, that the variation in Reynolds number did not affect the aerodynamic results within the accuracy of the balance.

Figure 14 shows the effect of the balance heaters by comparing data with the heaters off and on at 110 K with ambient temperature data. Except for the shift in axial-force coefficient that was previously noted in figure 11, the data are in good agreement.

The results for configuration 3, which had the insulating balance adapter replaced by the steel adapter and the convection shield removed, are presented in figure 15. As can be seen in figure 15(a), the data with the heaters on at a stagnation temperature of 110 K have a higher axial-force coefficient over the angle-of-attack range than the ambient temperature data. The difference is about 1 percent of the full-scale design load. The anomaly in the axial-force data at 110 K is thought to result from temperature gradients on the balance caused by removal of the convection shield and the associated higher power requirements for the balance heaters to maintain the temperature at 300 K on the balance at the thermocouple locations. There is also some discrepancy in the pitching-moment data, especially at 4° angle of attack. The data for configuration 3 in figure 15(b) with the heaters off are in better agreement for pitching moment and normal force than are the data with heaters on in figure 15(a). The axial-force data at 110 K in figure 15(b) contain a zero shift similar to that discussed earlier with regard to figure 11(b).

The results from tests of the three different configurations at ambient temperature are compared in figure 16 and are in excellent agreement.

Second Wind Tunnel Entry

The second cryogenic wind tunnel test with the HRC-2 balance was run during March 1981 in the 0.3-m TCT. For this test, the balance heaters were not used, since the results of the previous tunnel entry showed that the data with the heaters off were just as accurate as the data taken with heaters on. Also, based on the data obtained during the first tunnel entry, it was decided that the insulating adapter between the model and the balance was not necessary. The convection shield was retained, however, as the balance outputs were noticeably more stable with the shield in place, even when the balance heaters were off. Therefore, during the second tunnel entry, only configuration 2 was tested. As mentioned before, the balance was regaged and calibrated between the first and second tunnel entries as a result of continuing experimentation with gaging techniques as described in reference 9.

The results obtained at Mach numbers of 0.3 and 0.5 are contained in figures 17 through 19. The balance accuracy bands of ±0.5 percent of the full-scale loads are noted along the right-hand side of figures 17(a) and 17(b). The large differences in the sizes of the accuracy bands for the three components with changes in stagnation pressure and Mach number should be noted. Considering the magnitude of the accuracy bands, the agreement for the various test conditions in figure 17 for the case of constant Reynolds number is considered to be very good. The angle-of-attack range is less at a Mach number of 0.5 than at a Mach number of 0.3 to prevent the balance normal-force limit at the highest pressure from being exceeded.

Figure 18 shows the results at the different temperatures for the constant-pressure runs. Good agreement is seen except for the axial-force coefficient in figure 18(b) for a Mach number of 0.3 and the lowest stagnation pressure of 122 kPa. For this case, the balance accuracy of ±0.5 percent of full-scale axial design load translates to $C_A = \pm 0.0102$ for this relatively low aerodynamic loading. Figure 19(a) is a comparison of results at 300 K and a Mach number of 0.3 for two stagnation pressures, which result in a factor of 4 in the aerodynamic loads. The differences which can be noted in these runs and in the runs in figure 18(b) result from the inability of a single balance calibration to be applied over a large range of loads. This points out the possible need to calibrate a balance over more than one load range in order to improve data accuracy for tests at a low percentage of balance design loads. In figure 19(b), data for two runs are compared over a more similar load range and are found to be in excellent agreement for a Mach number of 0.5 and a total temperature of 300 K at two levels of stagnation pressure.

Figure 20 is a comparison of the results for two repeat runs at the same test conditions of a Mach number of 0.3 and a stagnation pressure of 488 kPa. These data are in excellent agreement over the entire range of angle of attack, indicating a high degree of repeatability provided by the tunnel control and instrumentation systems.

SUMMARY OF RESULTS

Aerodynamic evaluation tests have been made at ambient and at cryogenic temperatures with the latest Langley design of an internal strain-gage balance designed for operation in a cryogenic wind tunnel. A sharp leading-edge 75° delta-wing model was used to provide the aerodynamic loading for these tests. During the first tunnel entry, experiments were conducted with electrical resistance heaters, an insulating adapter between the model and the balance, and a convection shield for the balance. For the second tunnel entry, only the convection shield, which increased the stability of the balance output, was used. The evaluation was done by comparing the data at a tunnel stagnation temperature of 300 K with data taken at 200 K and 110 K while matching either the Reynolds number or the stagnation pressure. The data were obtained over a range of angle of attack up to about 29° and at Mach numbers of 0.3 and 0.5.

The wind tunnel tests show that it is possible to acquire accurate, repeatable force and moment data in a cryogenic wind tunnel while operating at steady-state thermal conditions with this latest design internal strain-gage balance, either with or without electrical resistance heaters being used to control balance temperature. The aerodynamic data taken without using the electrical heaters proved to be just as accurate as the data taken while using the electrical heaters.

The range of Reynolds number for this test did not produce any noticeable effects in the aerodynamic results for the delta-wing model within the limits of the balance accuracy.

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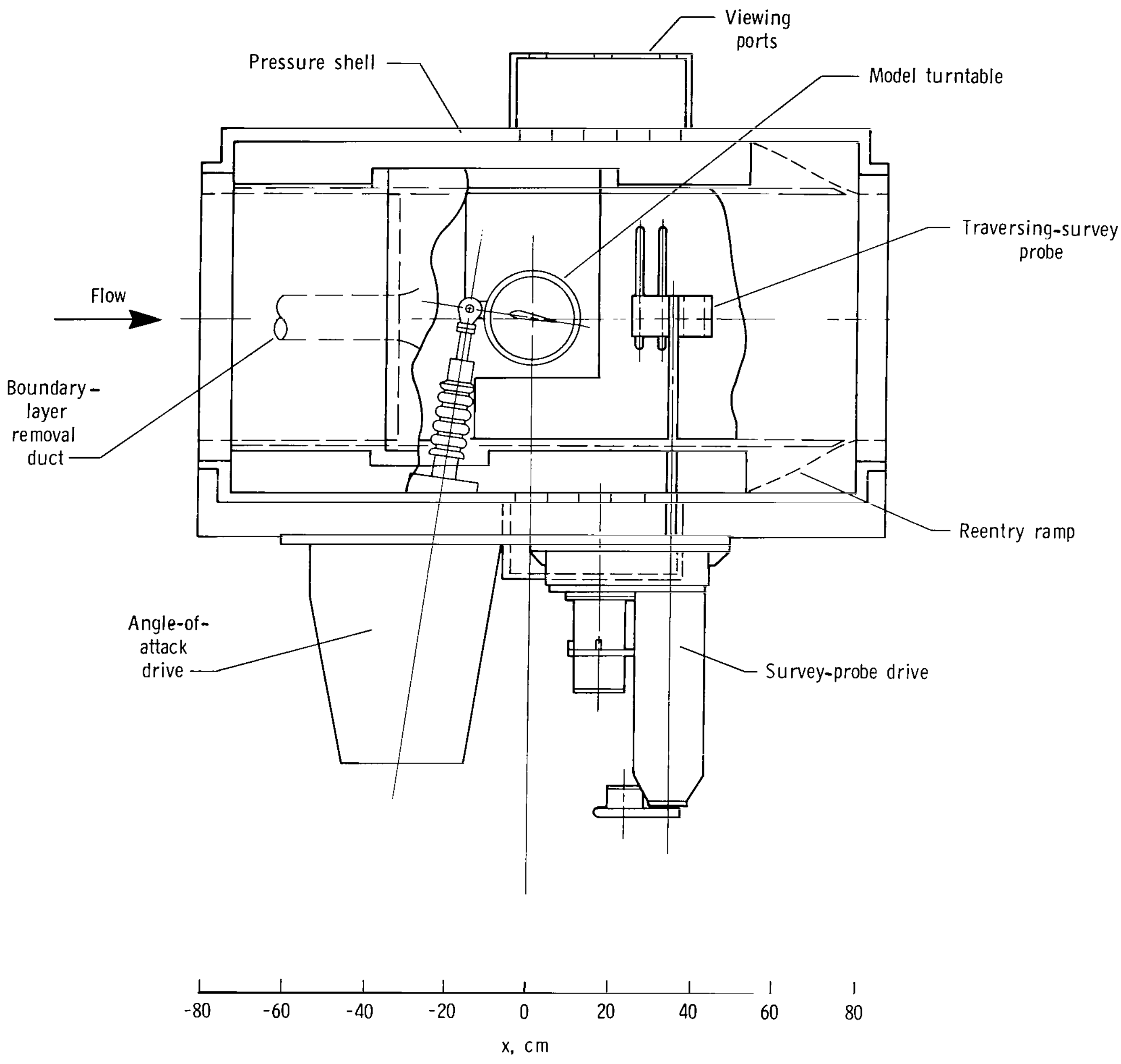

Figure 1.- Sketch of side view of two-dimensional test section of the Langley 0.3-m Transonic Cryogenic Tunnel.

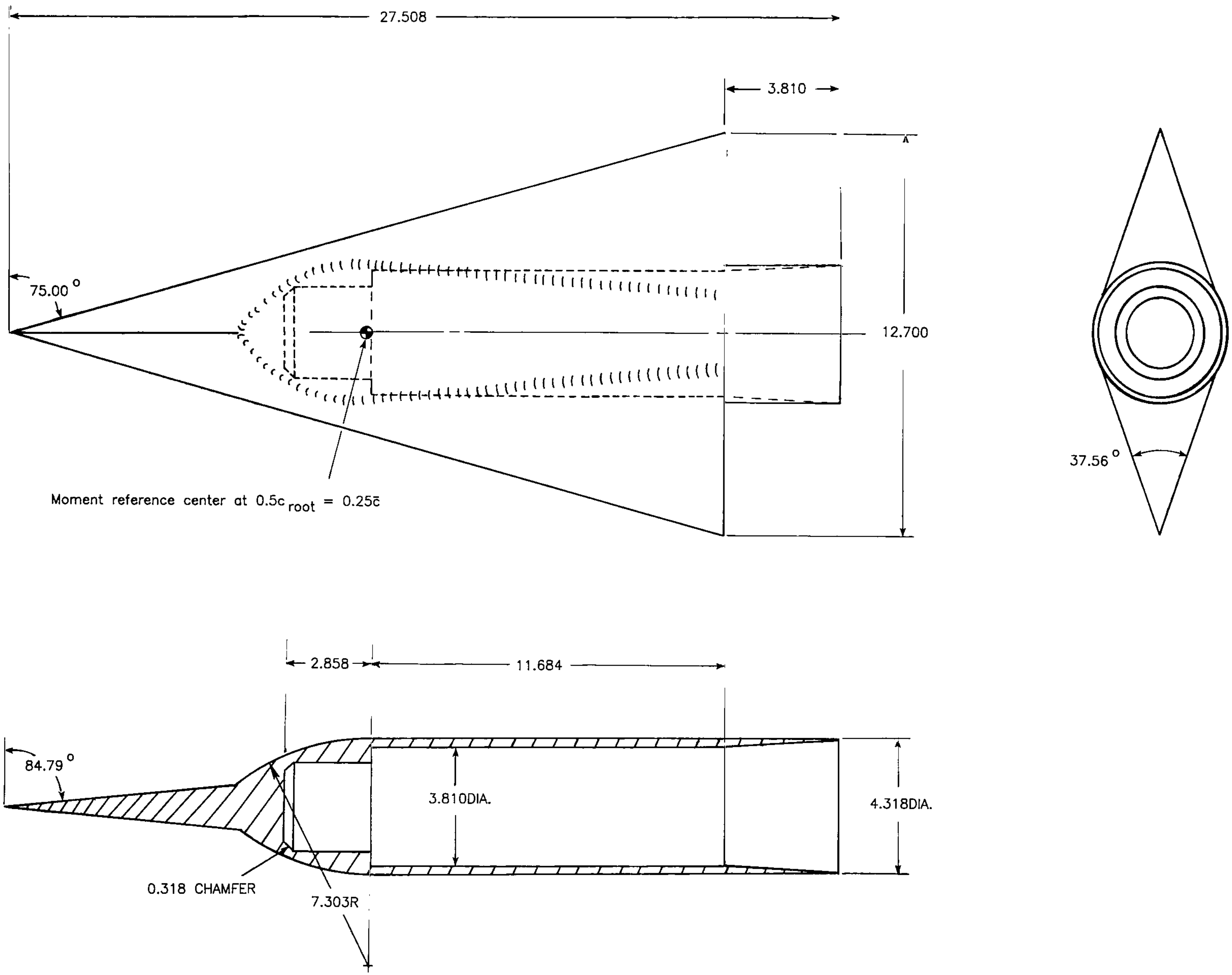

Figure 2.- Three-view drawing of model. (Dimensions are in centimeters.)

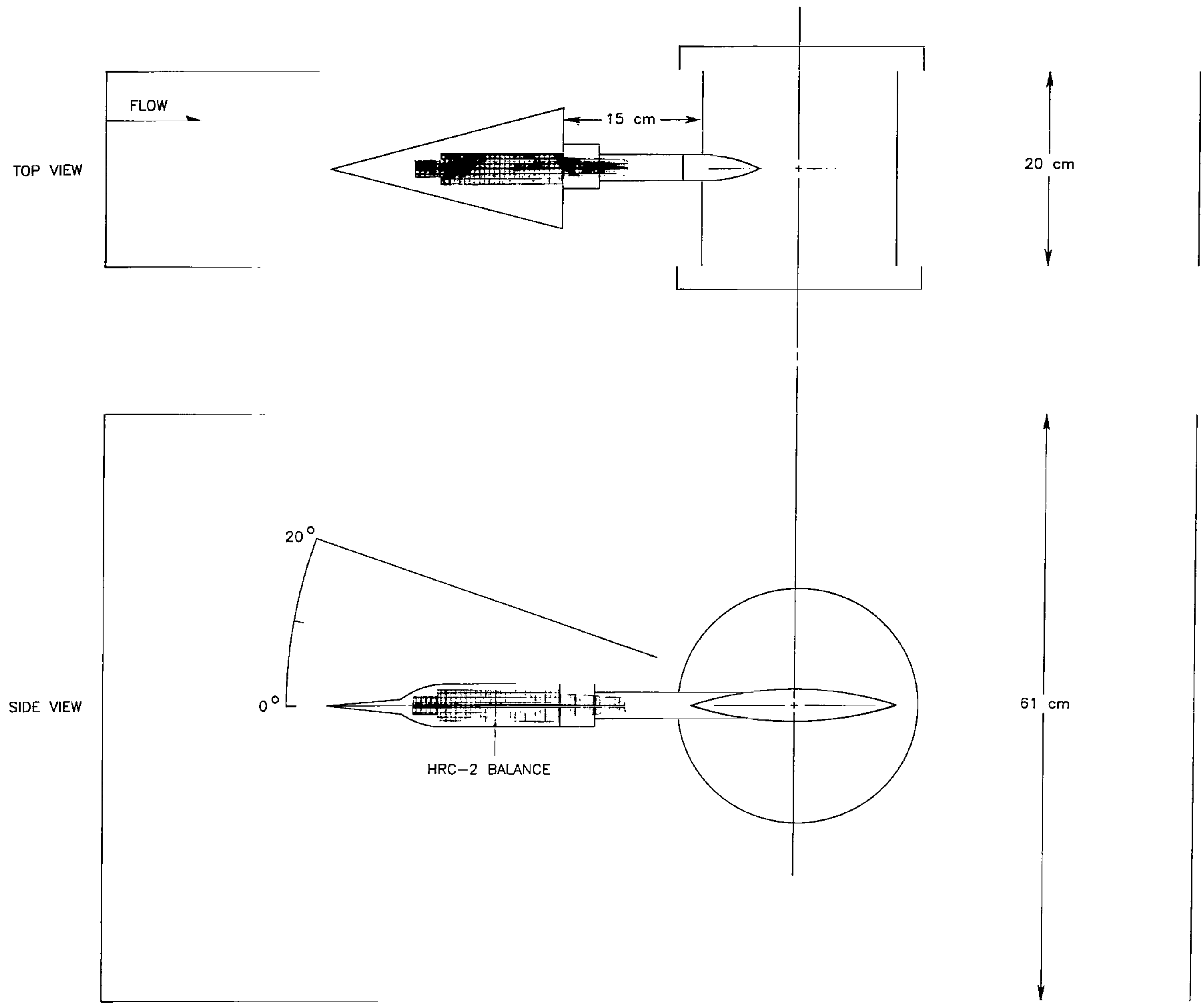

Figure 3.- Sketch of arrangement of model, sting, and strut support in the Langley 0.3-m Transonic Cryogenic Tunnel.

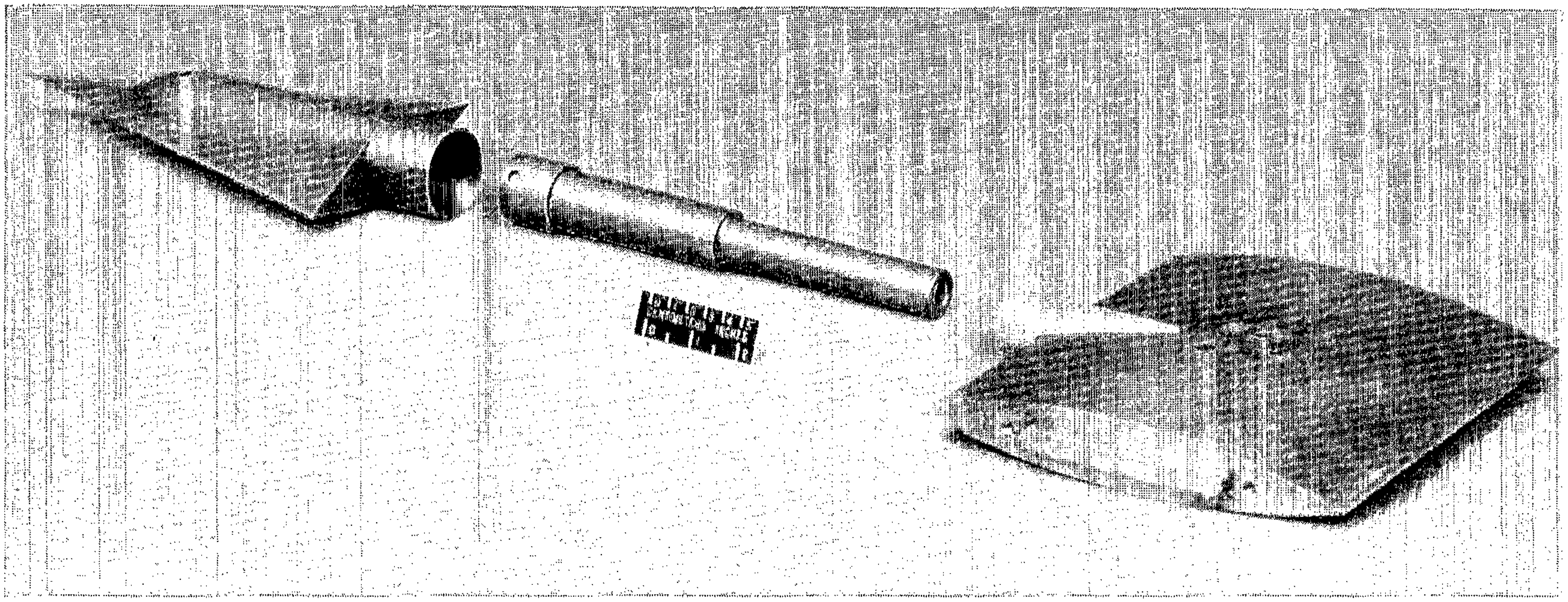

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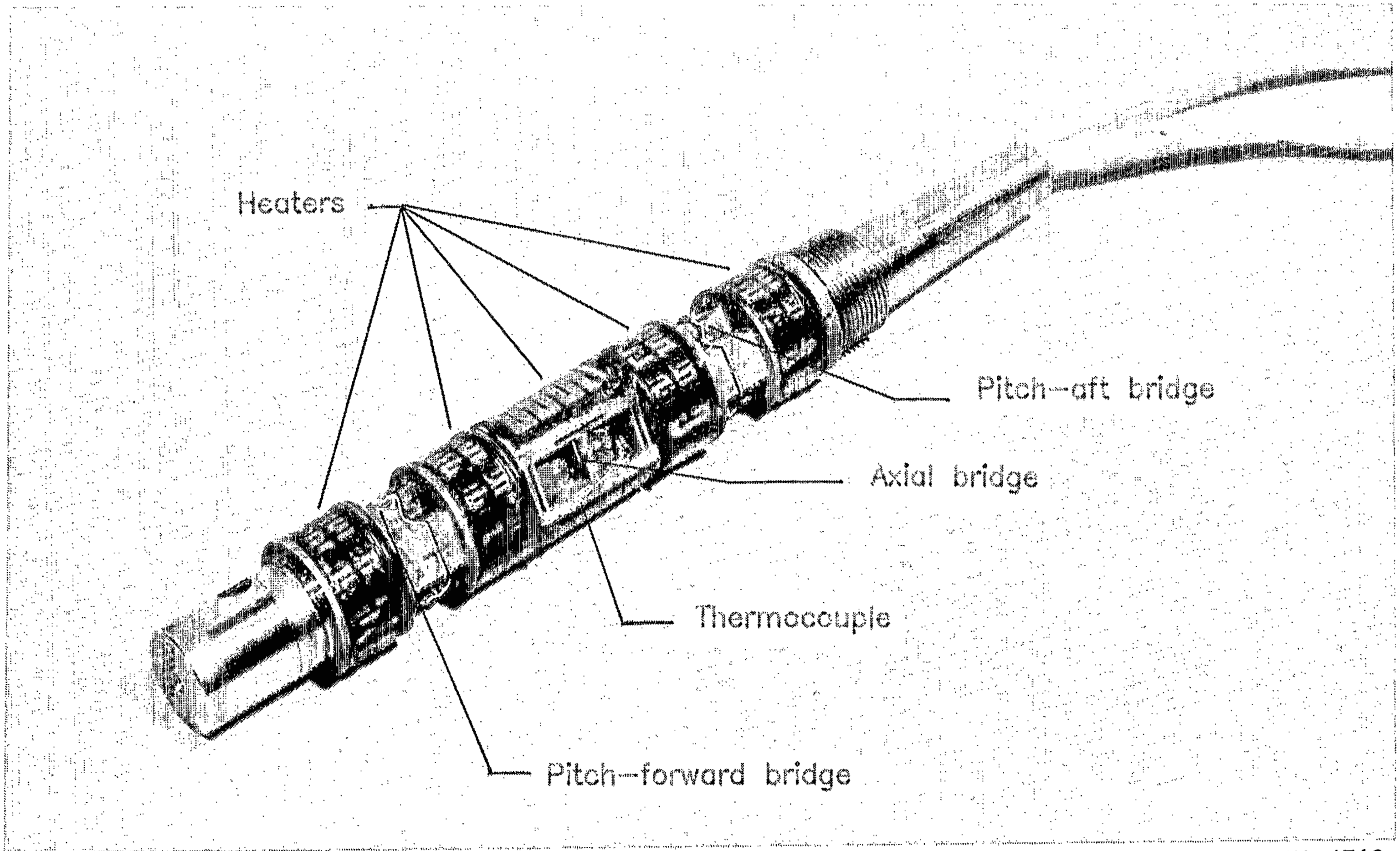
Figure 4.- Photograph of model, sting, and support strut.



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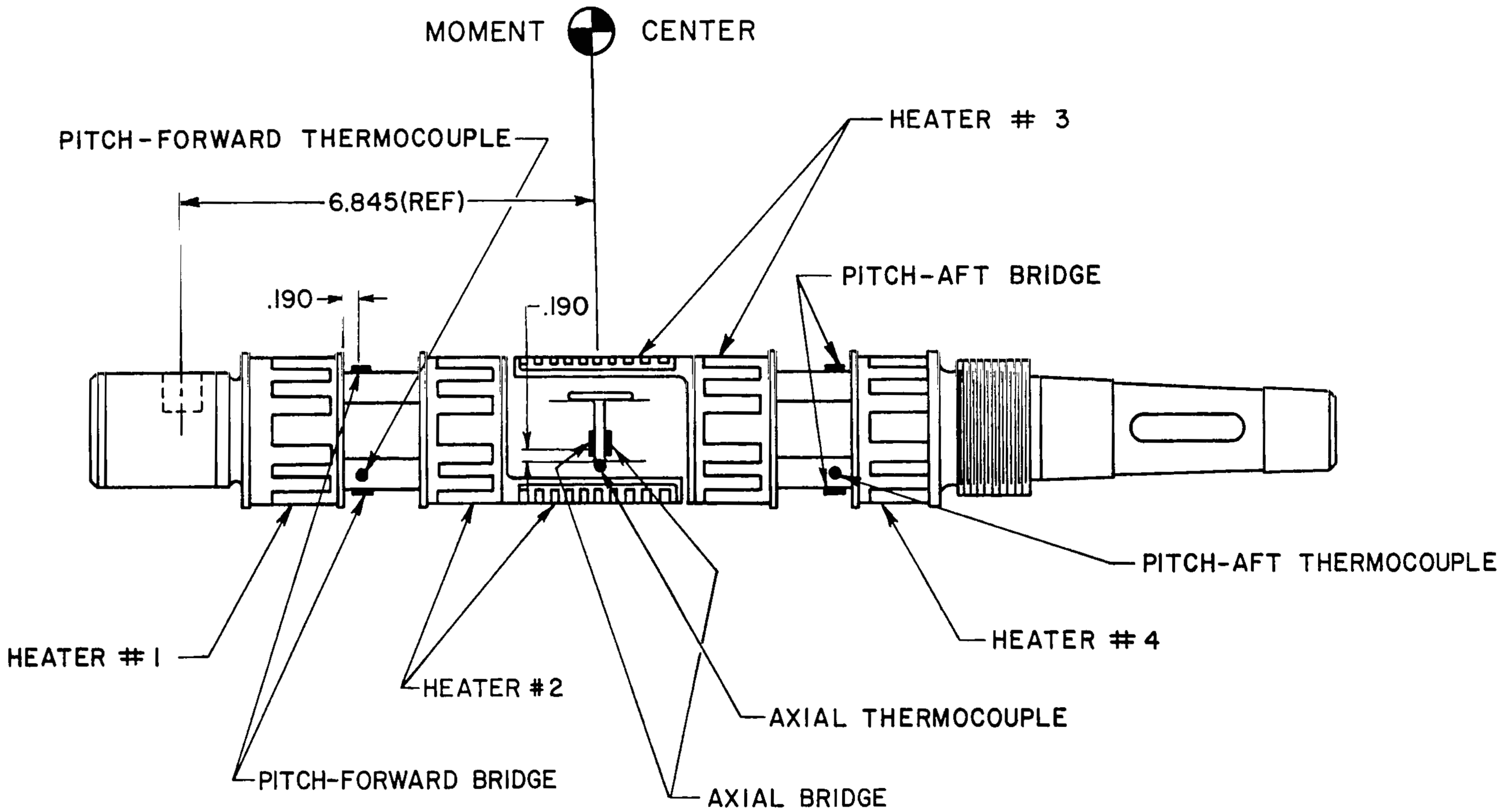
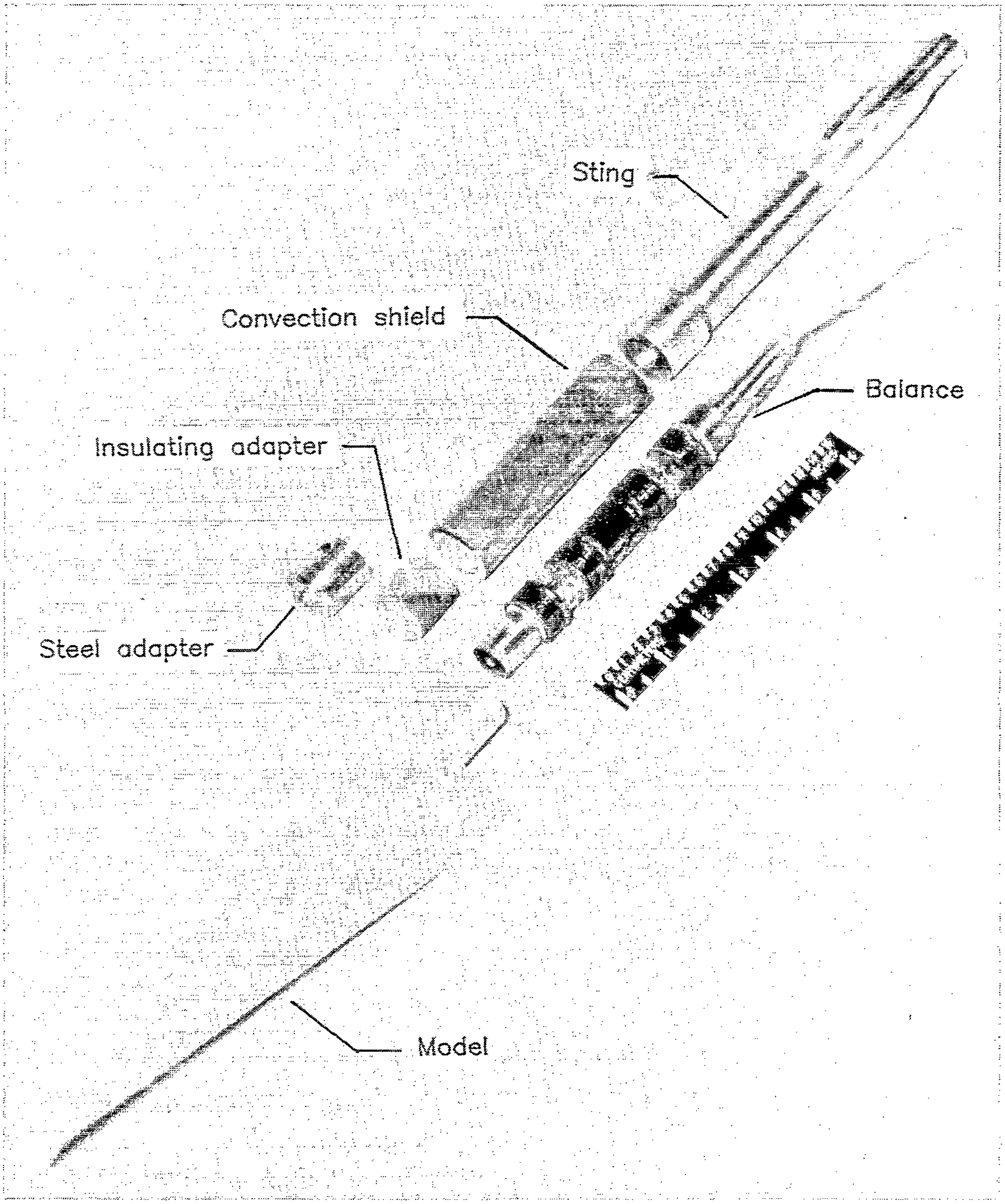
(a) Photograph of balance.

Figure 5.- Strain-gage balance HRC-2.



(b) Schematic of balance. (Dimensions are in centimeters.)

Figure 5.- Concluded.



L-79-5710

Figure 6.- Photograph of model, balance, shield, adapters, and sting.

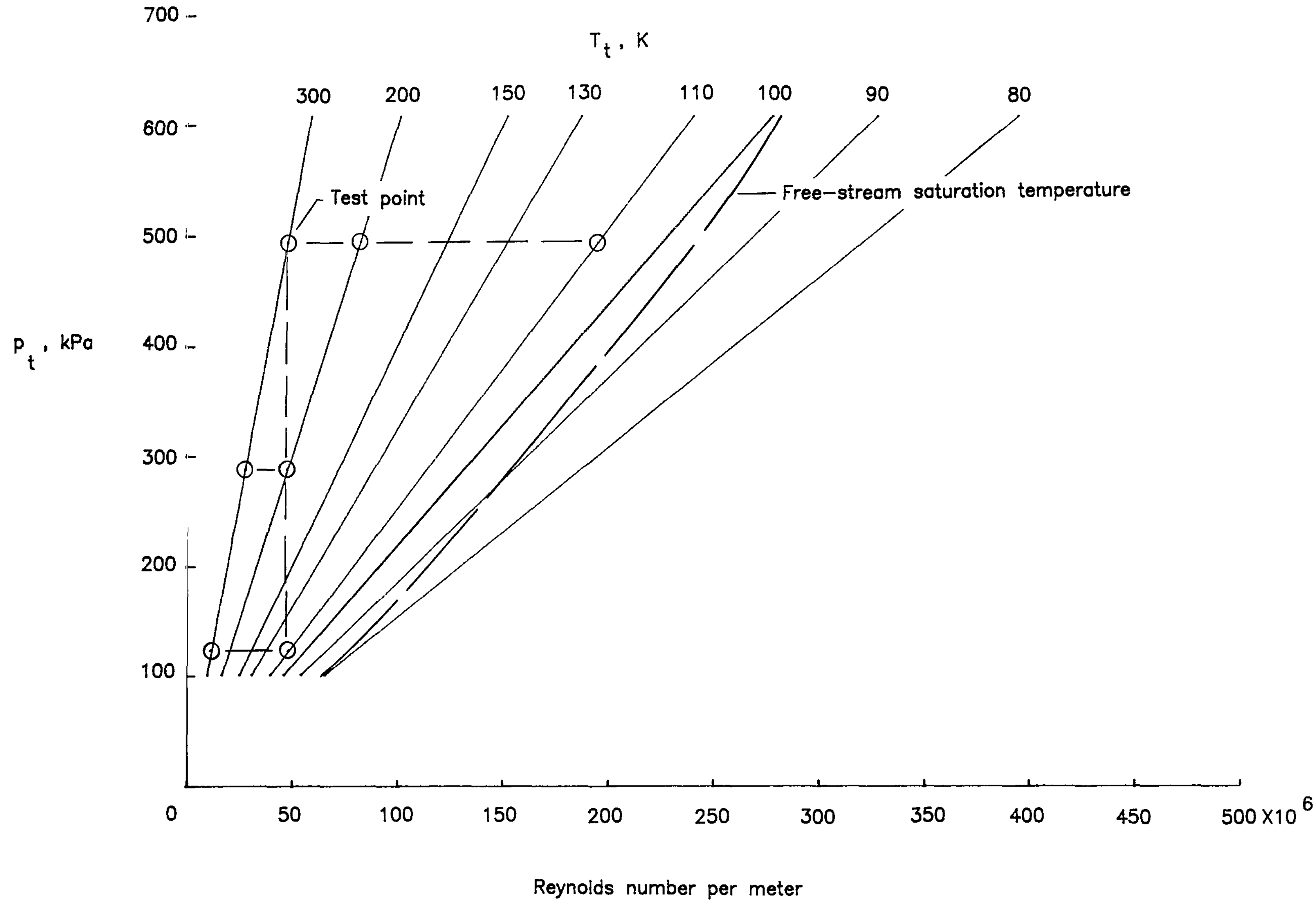
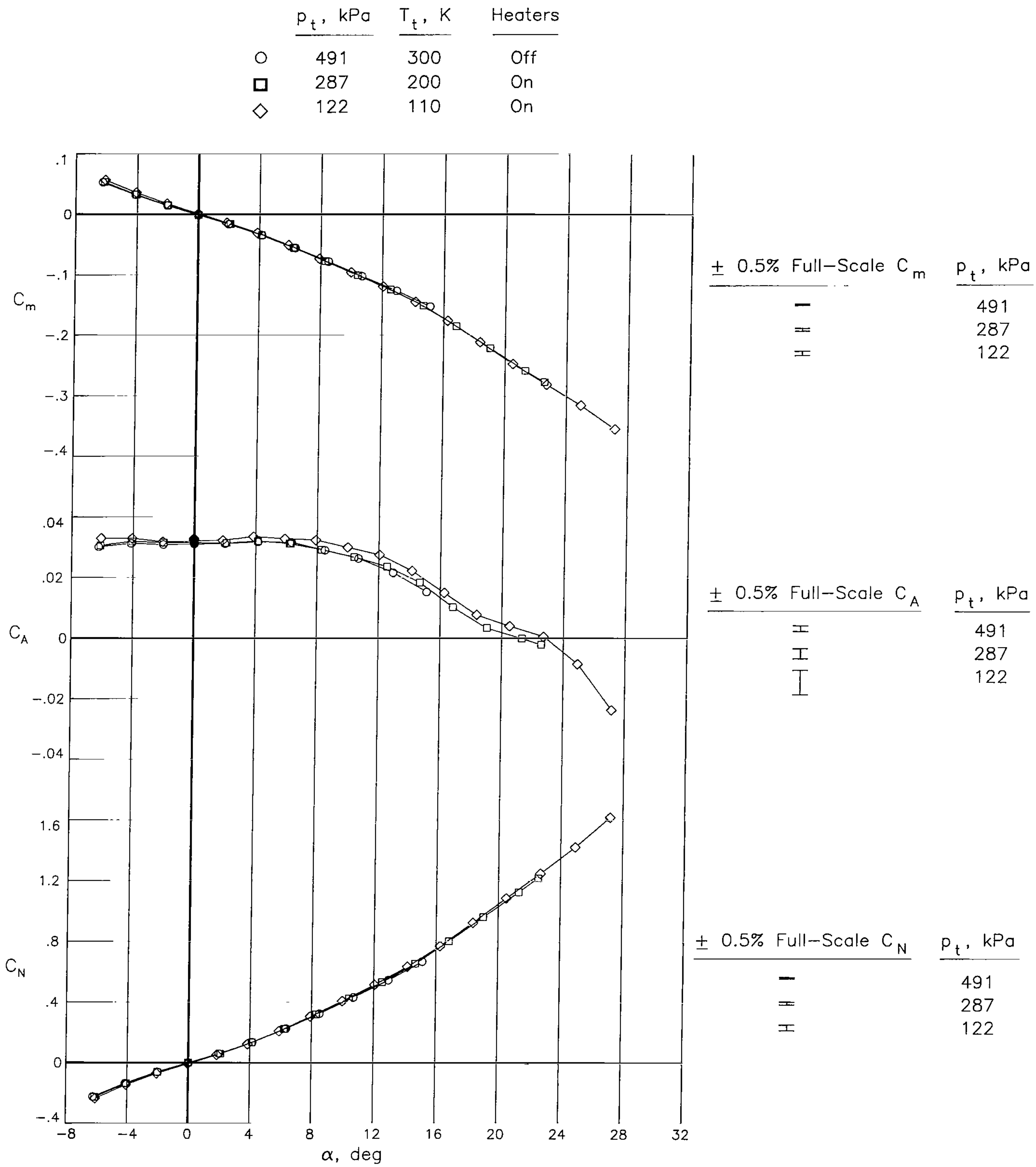
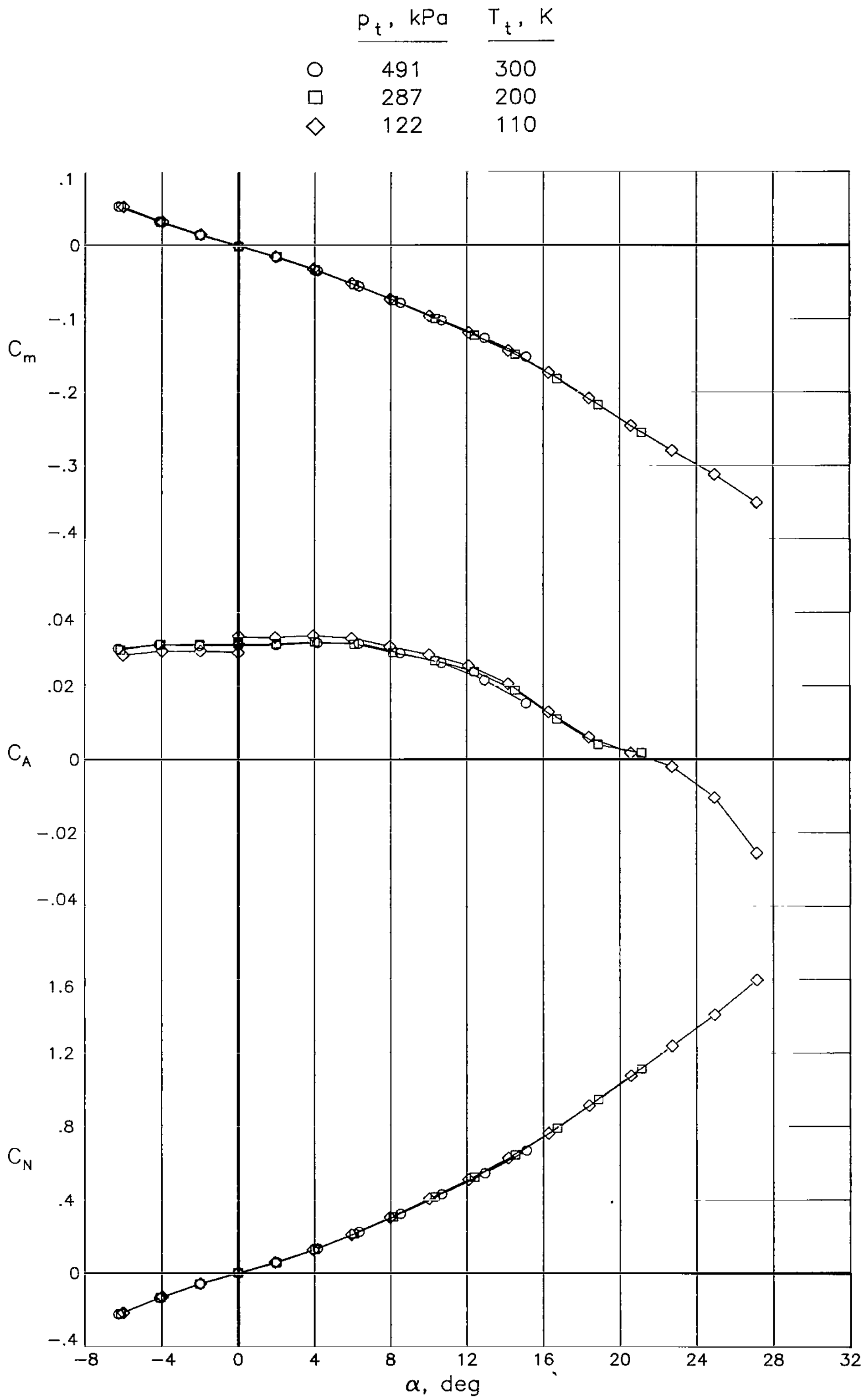


Figure 7.- Envelope of test conditions in the Langley 0.3-m Transonic Cryogenic Tunnel for a Mach number of 0.5.



(a) Balance heaters on, as required.

Figure 8.- Comparison of results for configuration 1 at $M = 0.5$ and $R = 7.60 \times 10^6$.



(b) Balance heaters off.

Figure 8.- Concluded.

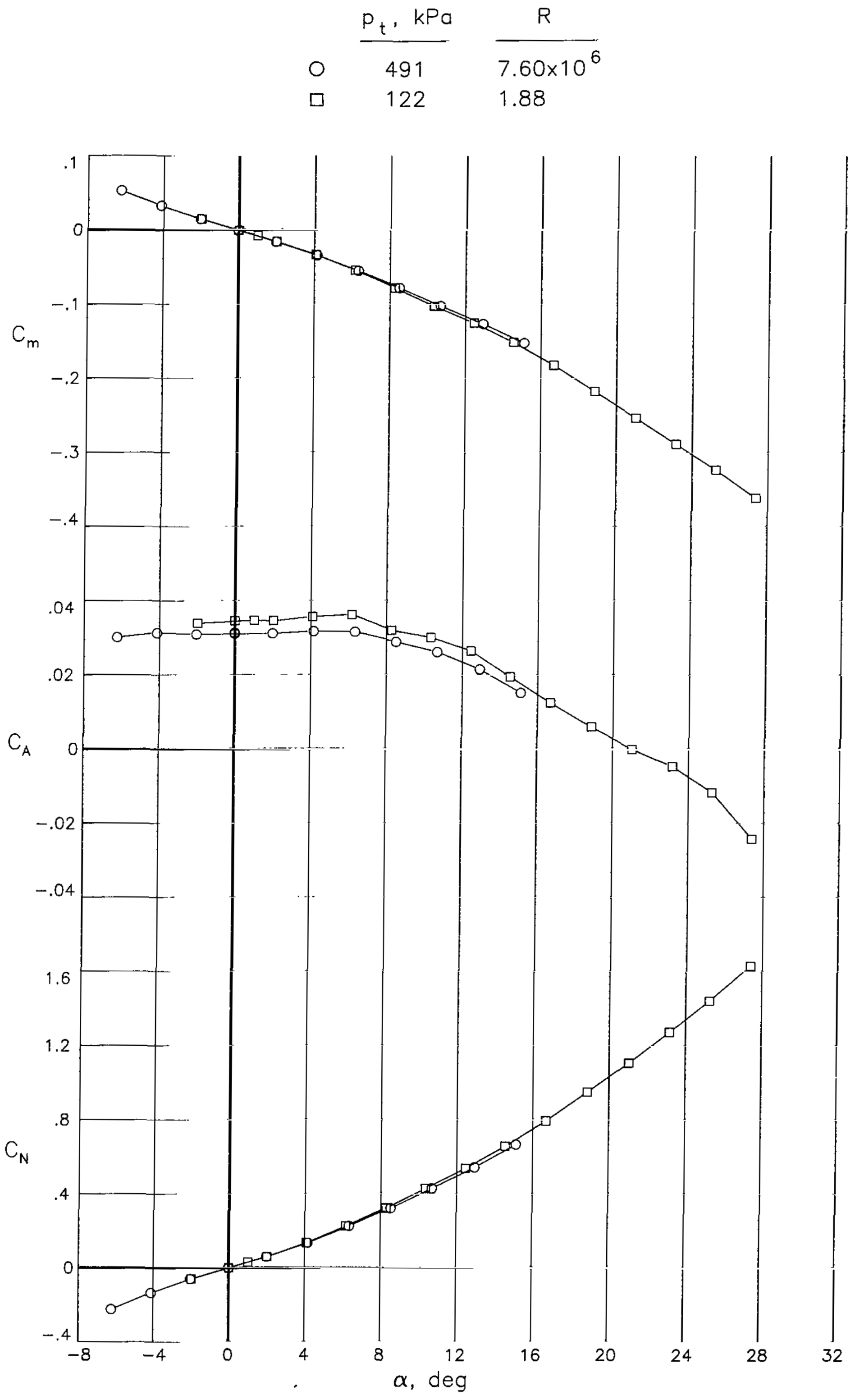


Figure 9.- Comparison of results for configuration 1 with balance heaters off at $M = 0.5$ and $T_t = 300$ K.

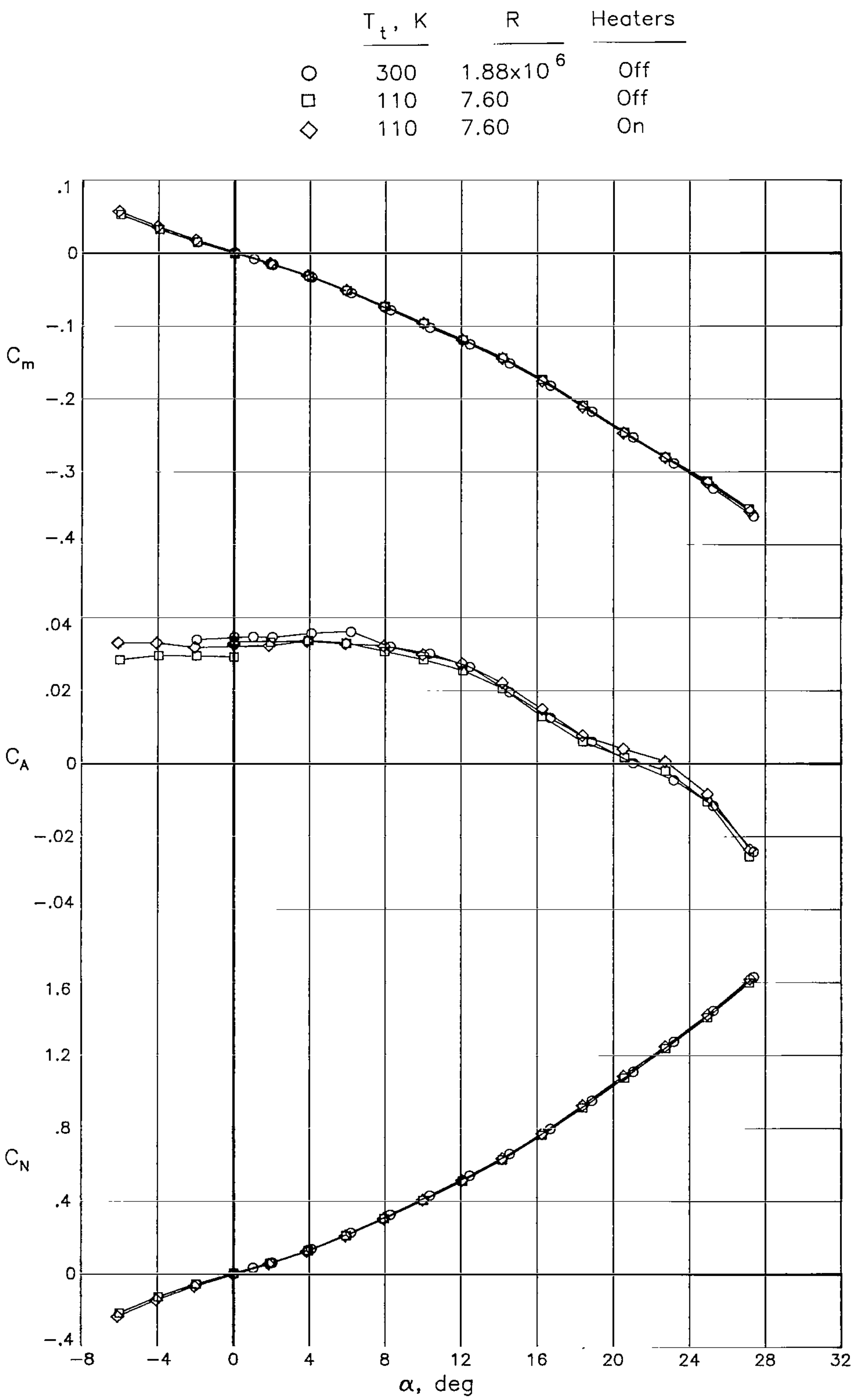
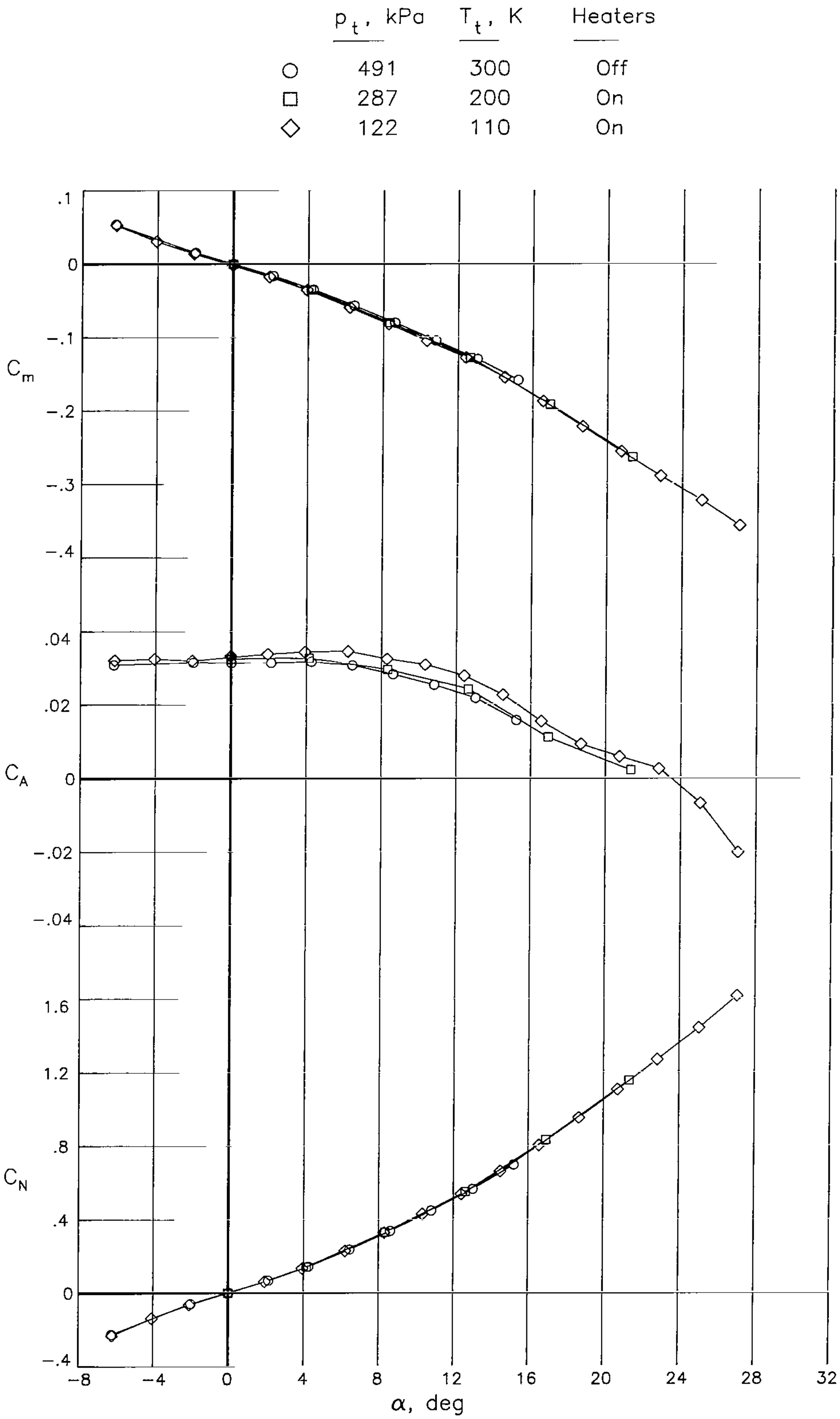
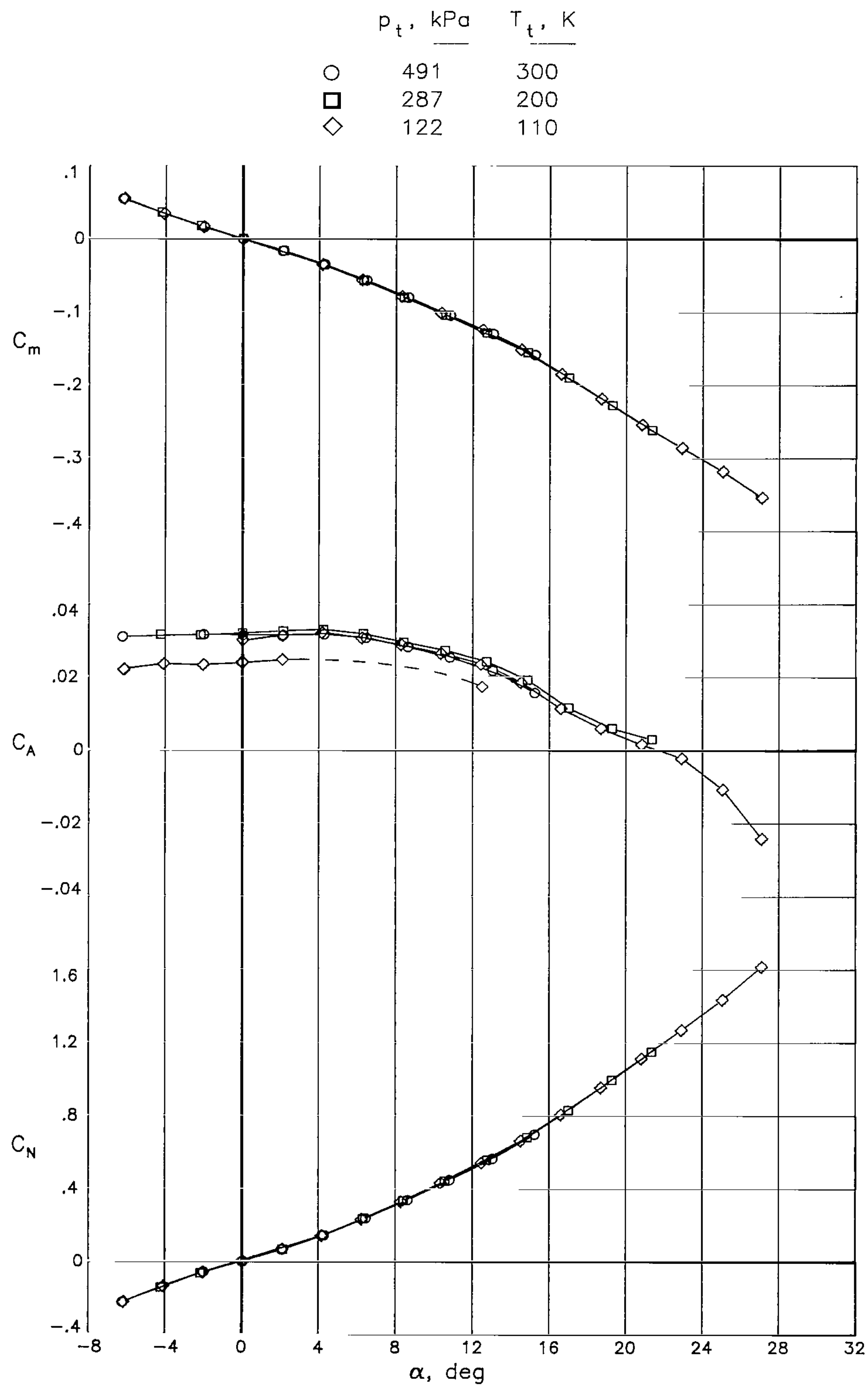


Figure 10.- Comparison of results for configuration 1 with balance heaters off and on at $M = 0.5$ and $p_t = 122$ kPa.



(a) Balance heaters on, as required.

Figure 11.- Comparison of results for configuration 2 at $M = 0.5$ and $R = 7.60 \times 10^6$.



(b) Balance heaters off.

Figure 11.- Concluded.

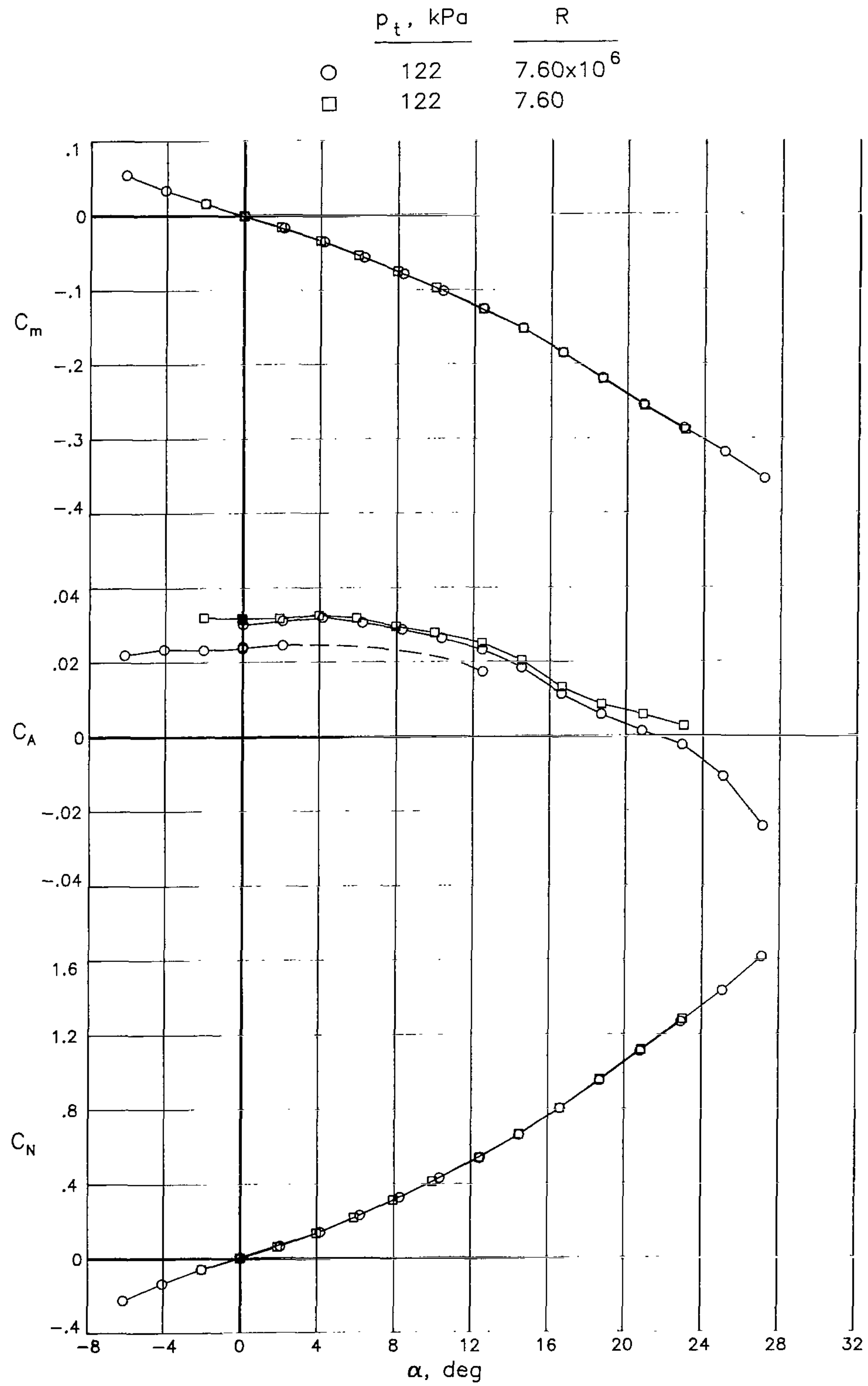


Figure 12.- Comparison of results for repeat runs for configuration 2 with balance heaters off at $M = 0.5$ and $T_t = 110$ K.

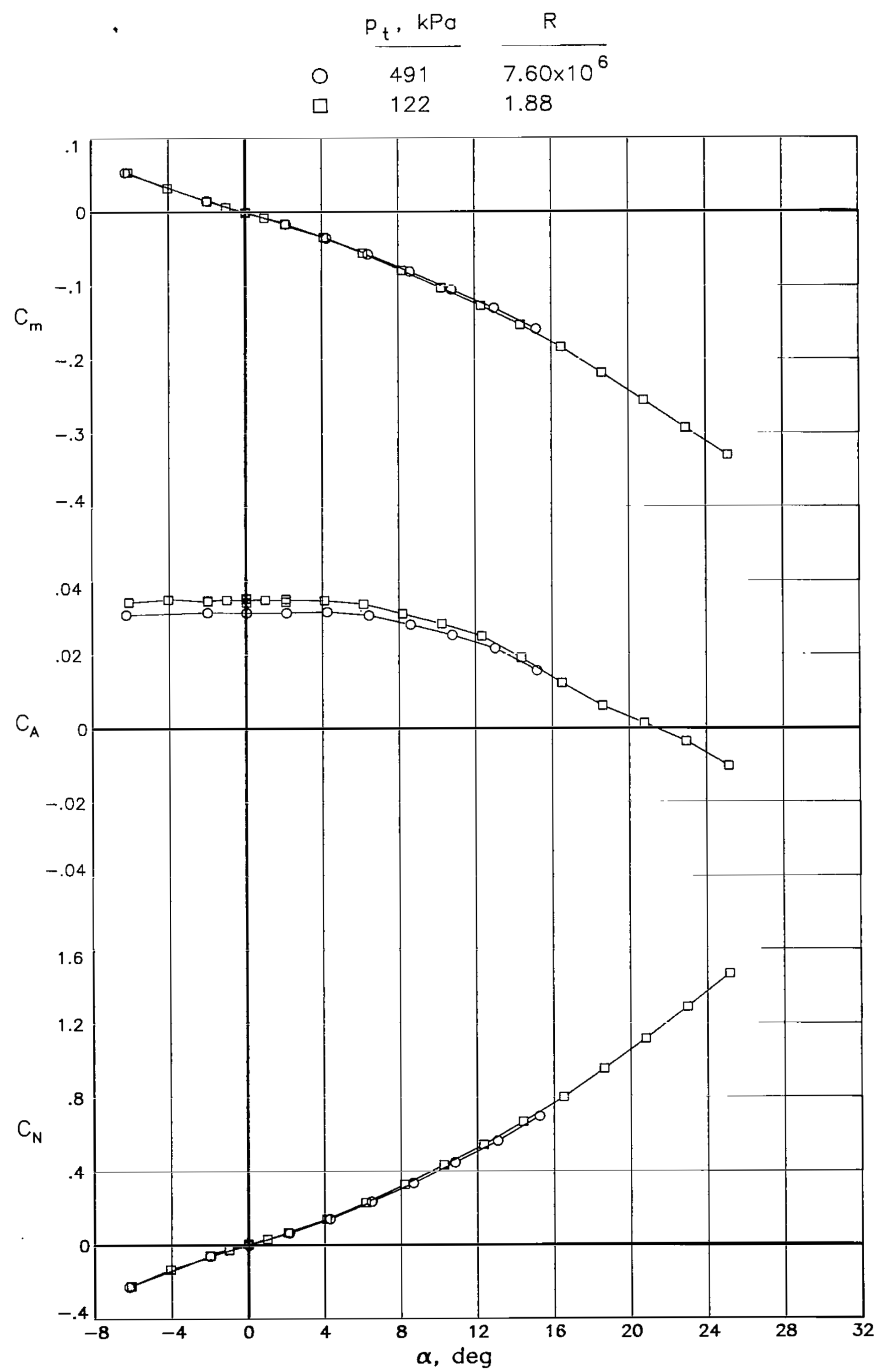


Figure 13.- Comparison of results for configuration 2 with balance heaters off at $M = 0.5$ and $T_t = 300$ K.

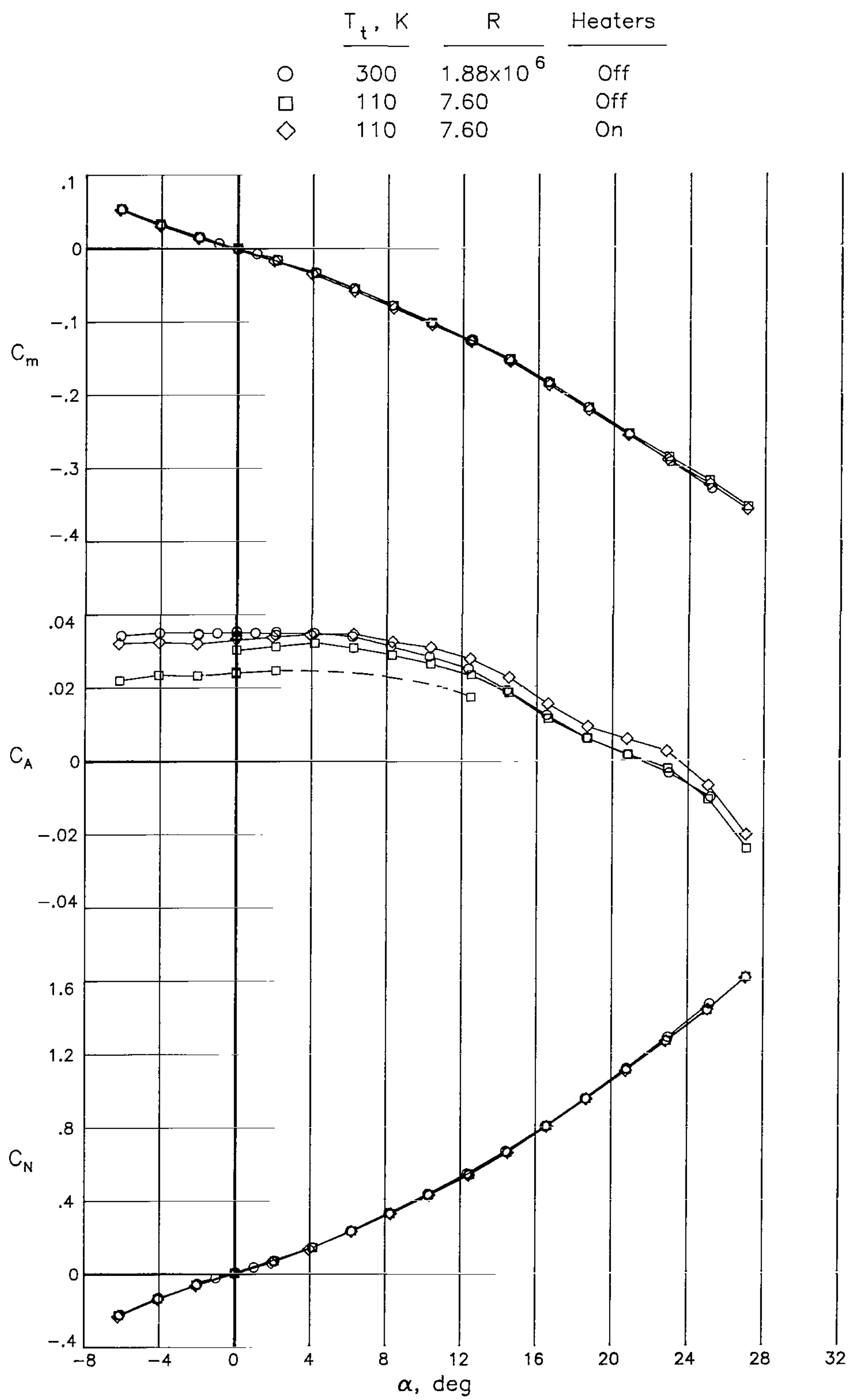
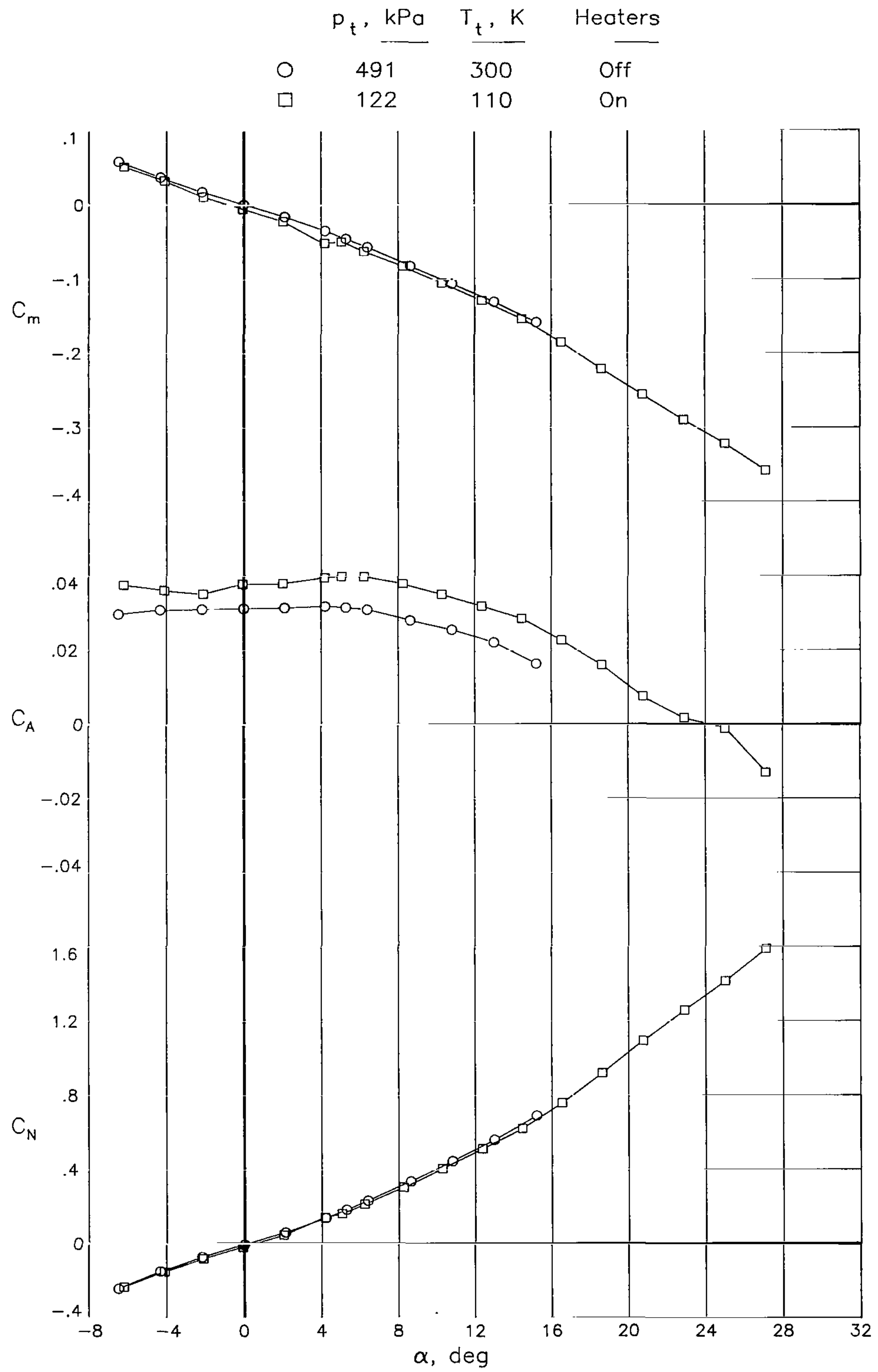
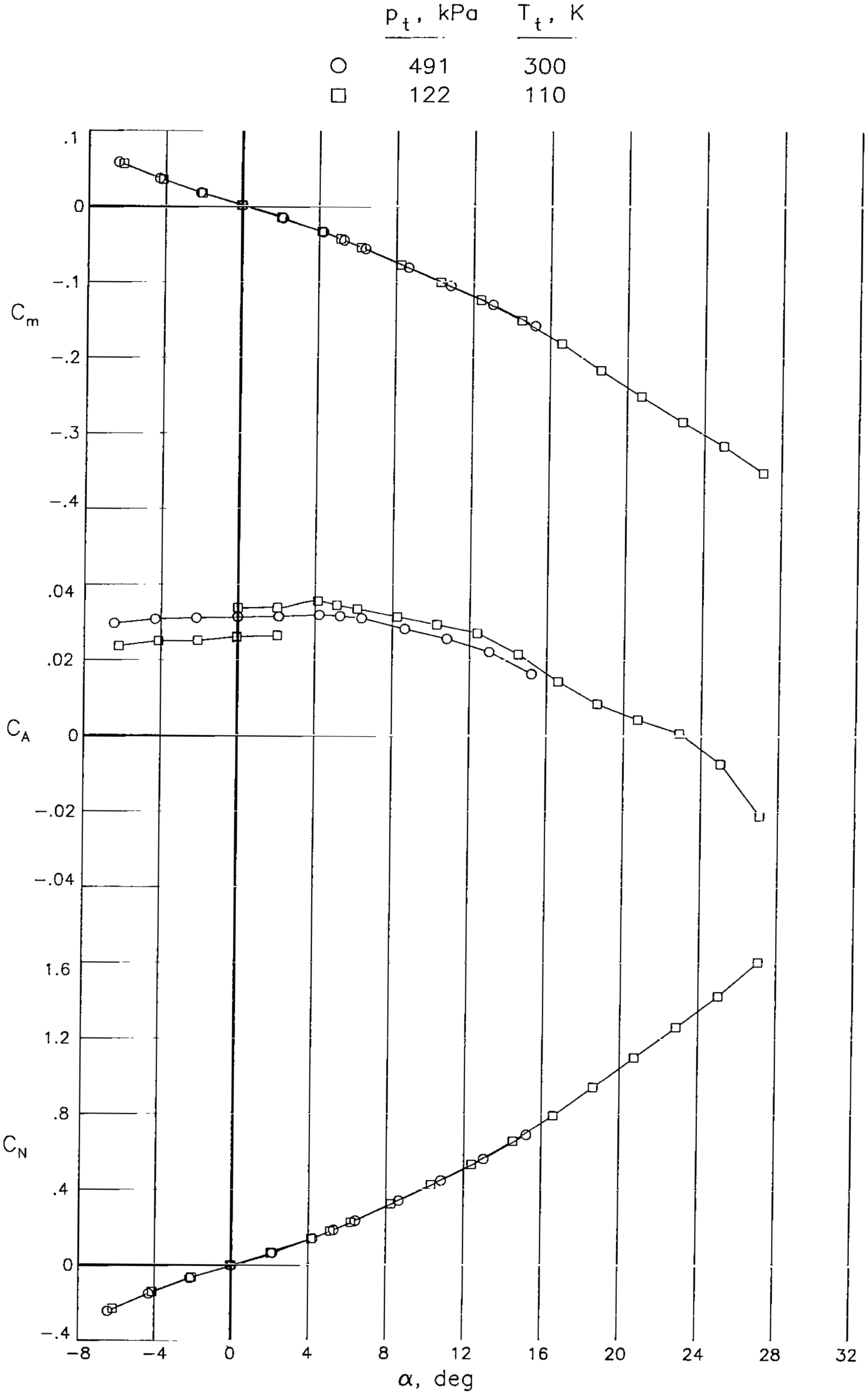


Figure 14.- Comparison of results for configuration 2 with balance heaters off and on at $M = 0.5$ and $P_t = 122$ kPa.



(a) Balance heaters on, as required.

Figure 15.- Comparison of results for configuration 3 at $M = 0.5$ and $R = 7.60 \times 10^6$.



(b) Balance heaters off.

Figure 15.- Concluded.

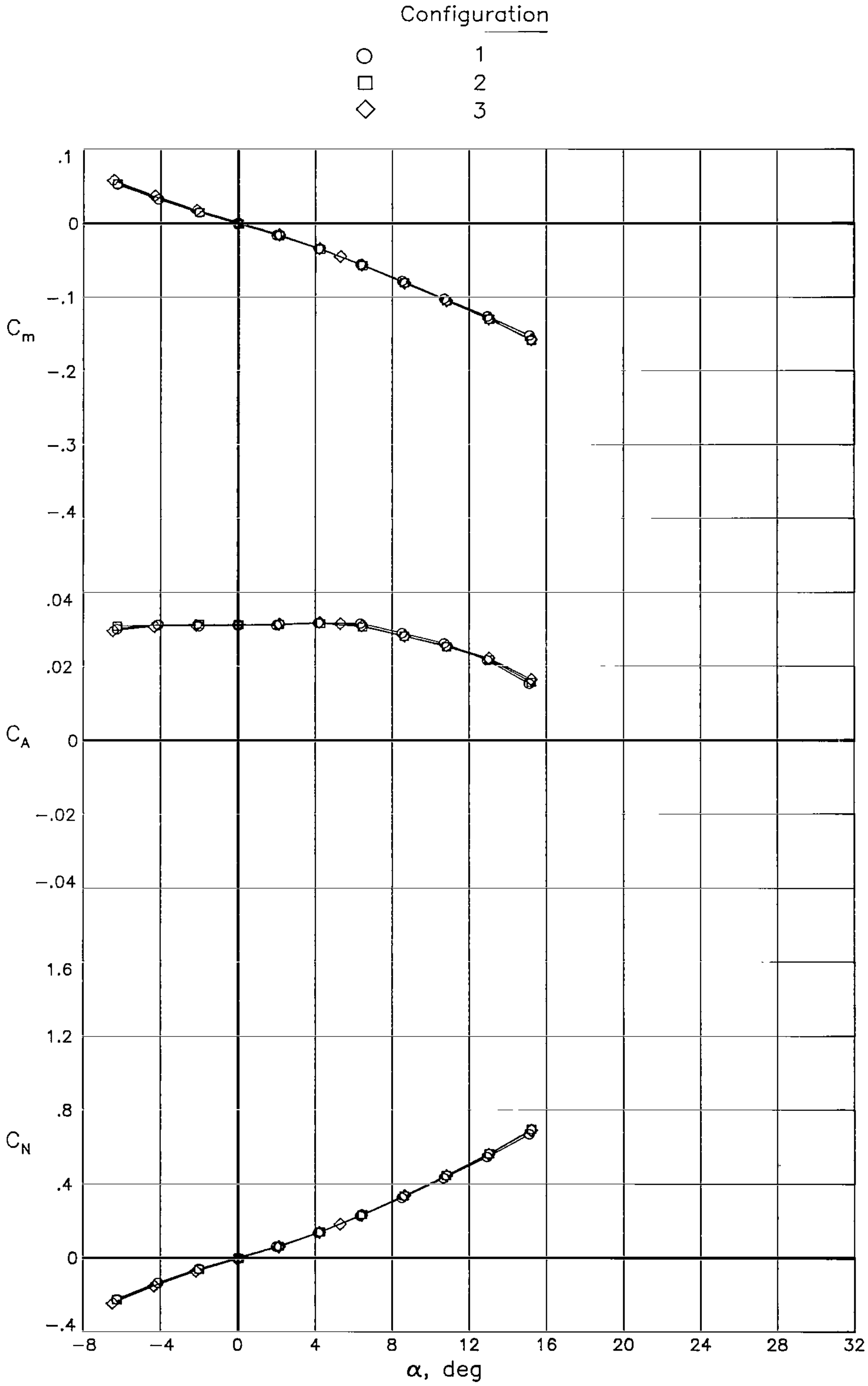
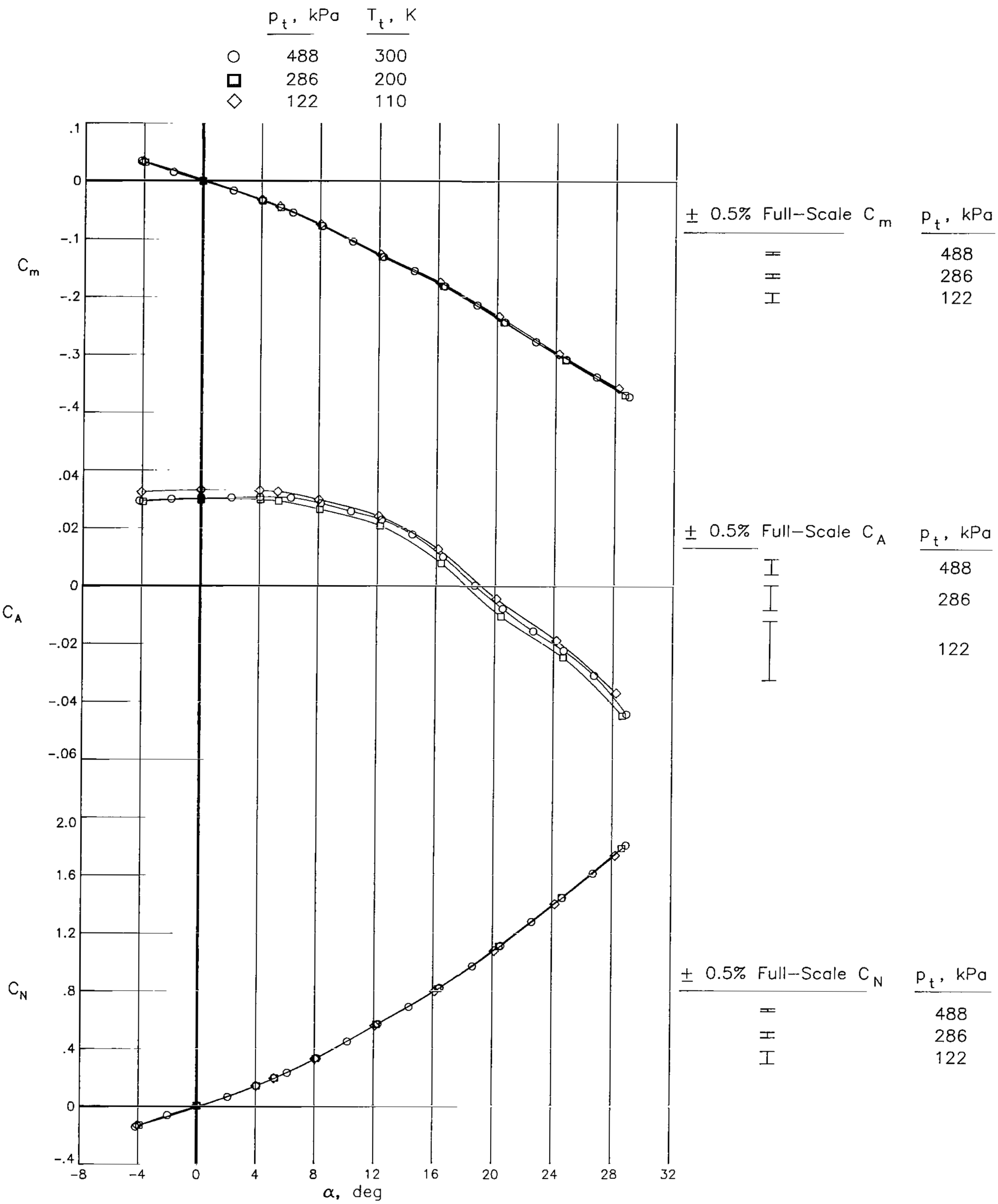
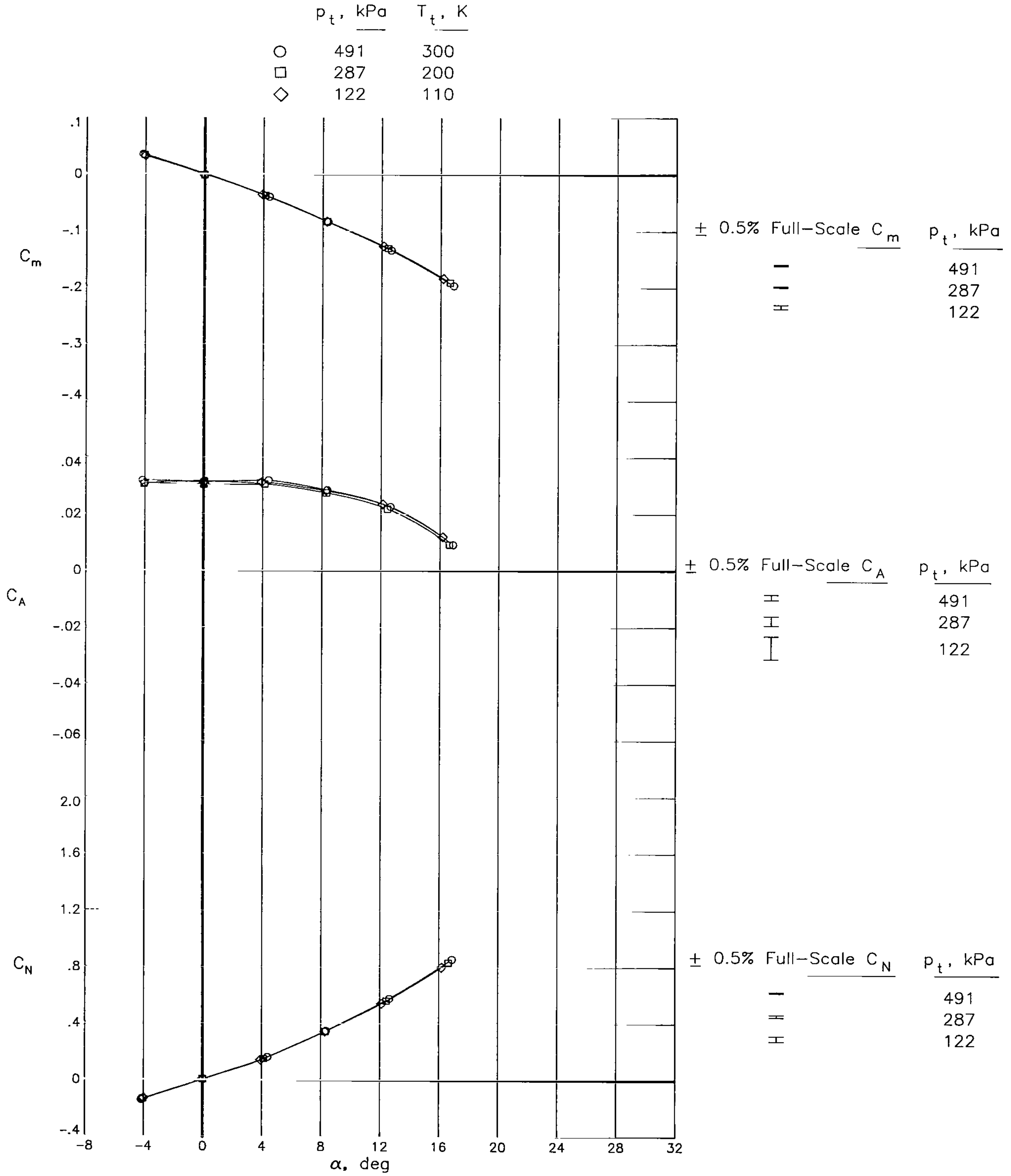


Figure 16.- Comparison of results for configurations 1, 2, and 3 with balance heaters off at $M = 0.5$, $p_t = 491$ kPa, and $T_t = 300$ K.



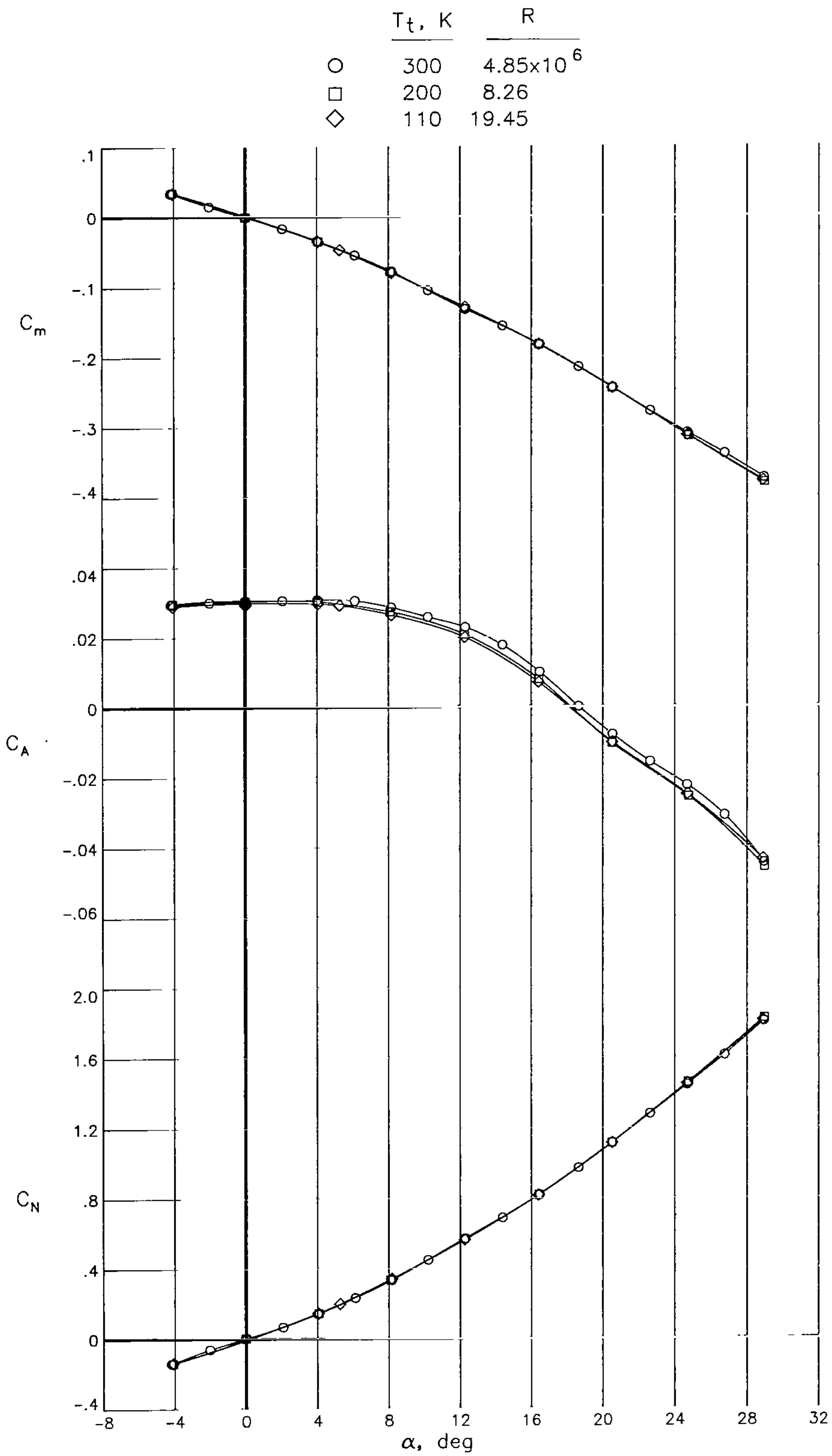
(a) M = 0.3; R = 4.85 × 10^6.

Figure 17.- Comparison of results for configuration 2 with balance heaters off at constant Reynolds number.



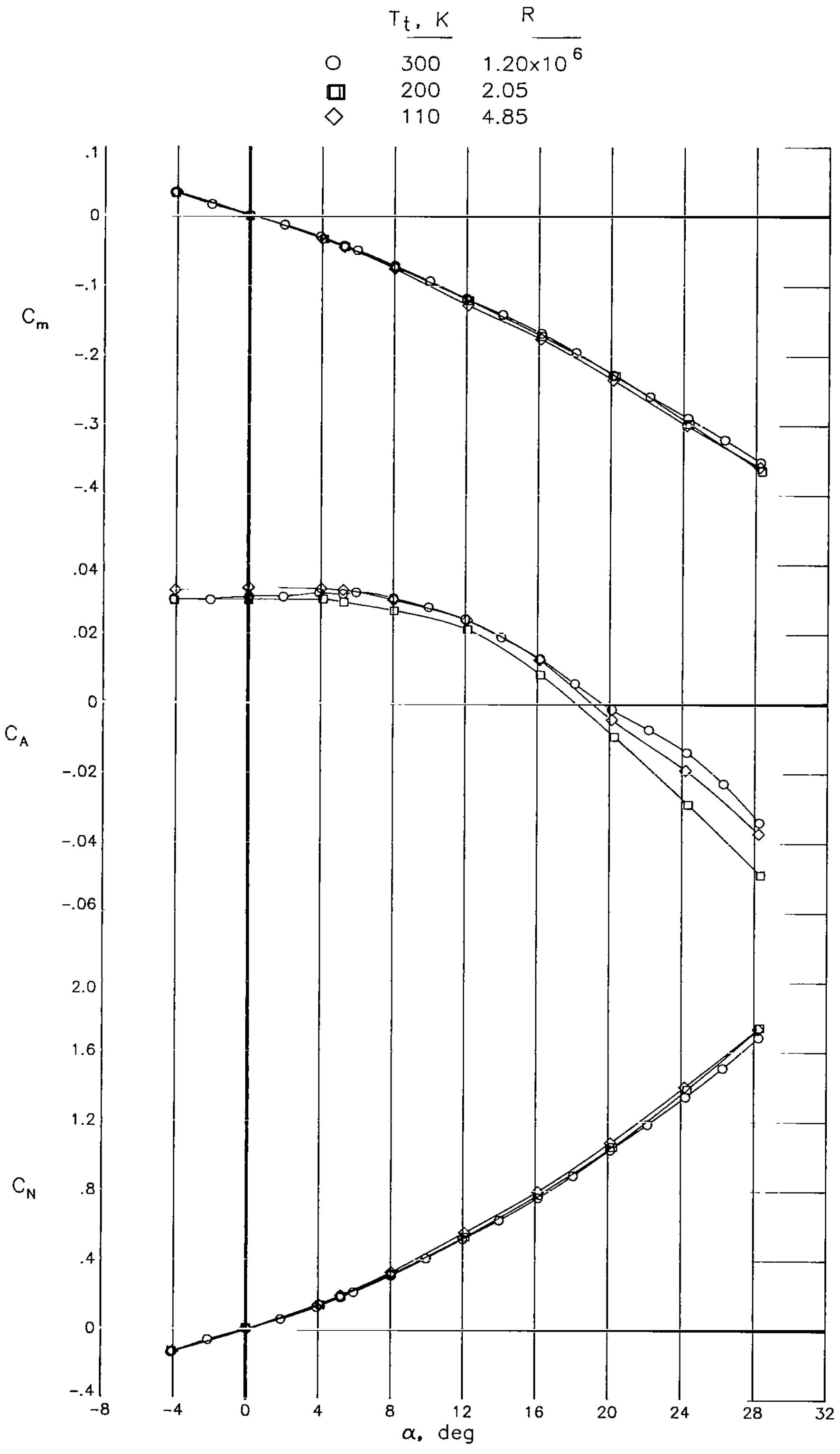
(b) M = 0.5; R = 7.60 × 10^6.

Figure 17.- Concluded.



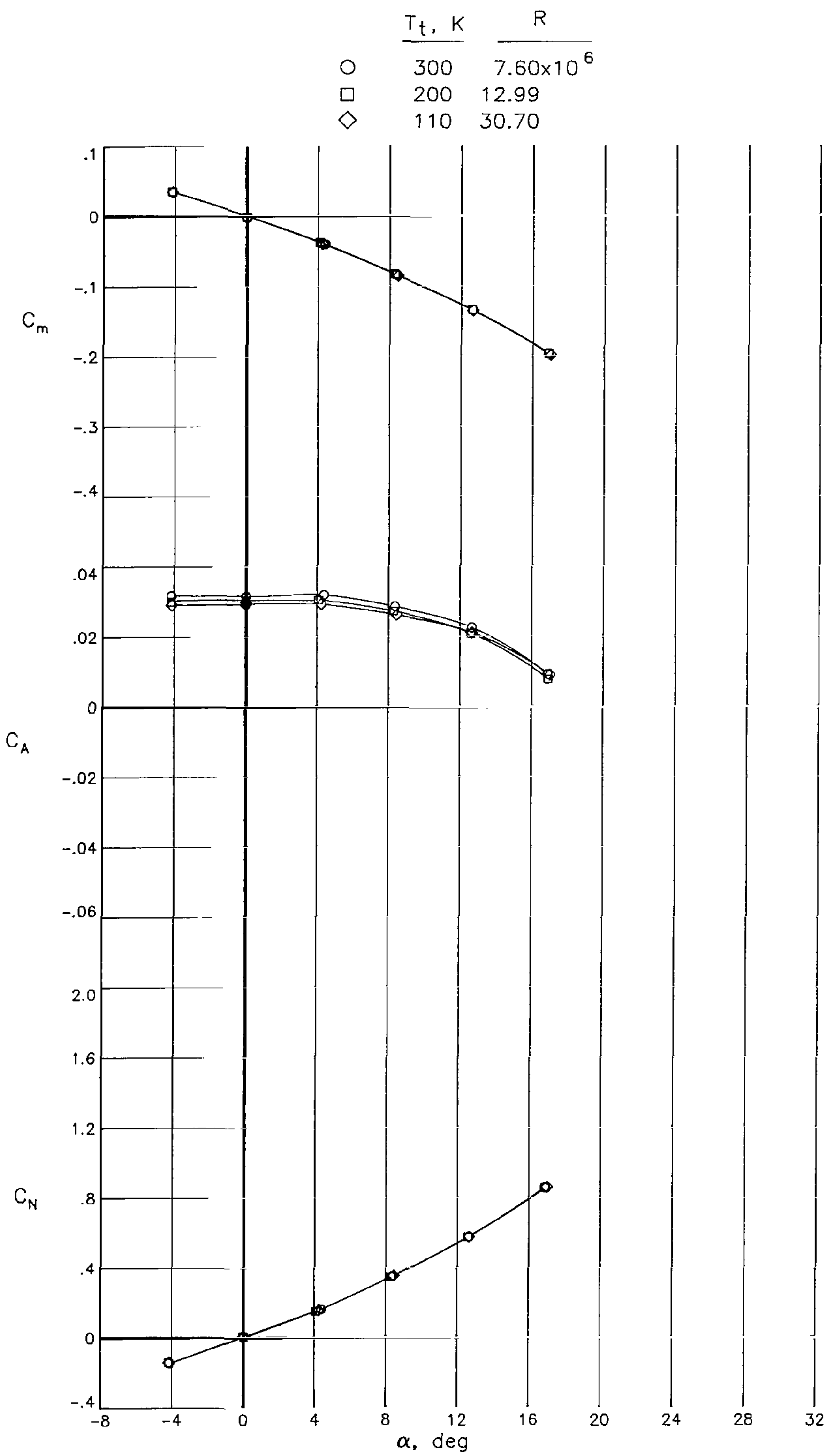
(a) M = 0.3; p_t = 488 kPa.

Figure 18.- Comparison of results for configuration 2 with balance heaters off at constant pressure.



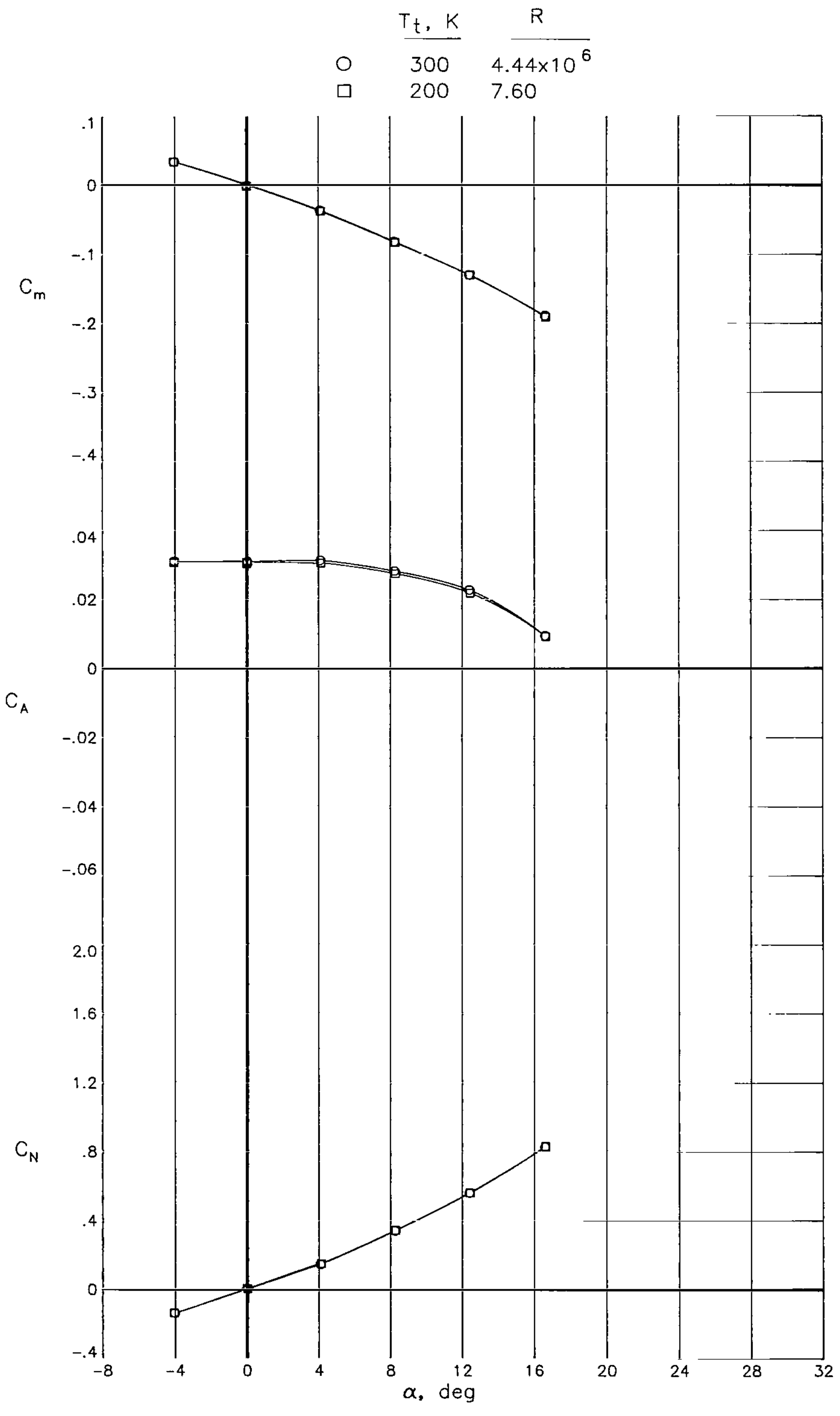
(b) M = 0.3; p_t = 122 kPa.

Figure 18.- Continued.



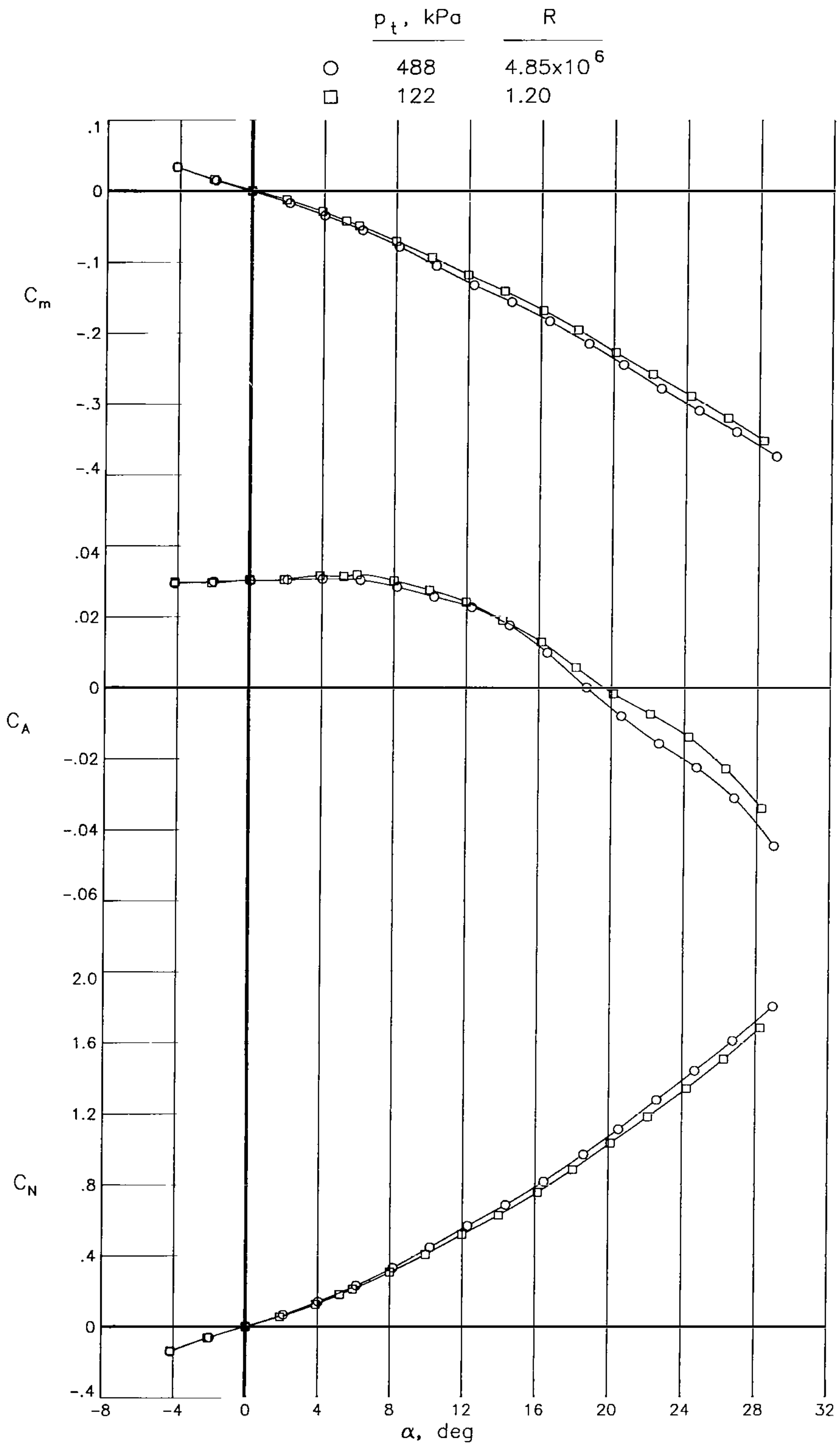
(c) M = 0.5; p_t = 491 kPa.

Figure 18.- Continued.



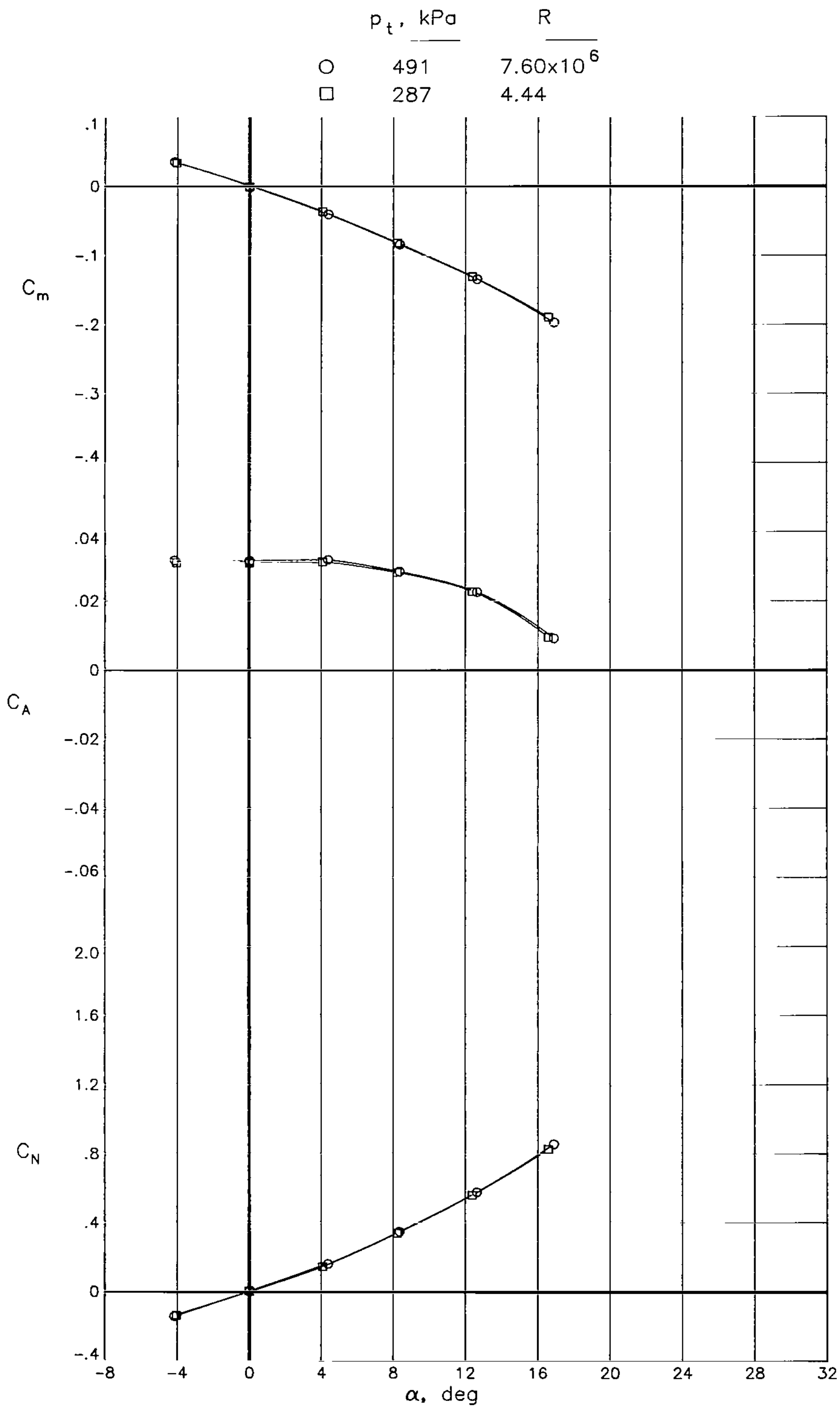
(d) $M = 0.5$; $p_t = 287$ kPa.

Figure 18.- Concluded.



(a) M = 0.3.

Figure 19.- Comparison of results for configuration 2 with balance heaters off at T_t = 300 K.



(b) M = 0.5.

Figure 19.- Concluded.

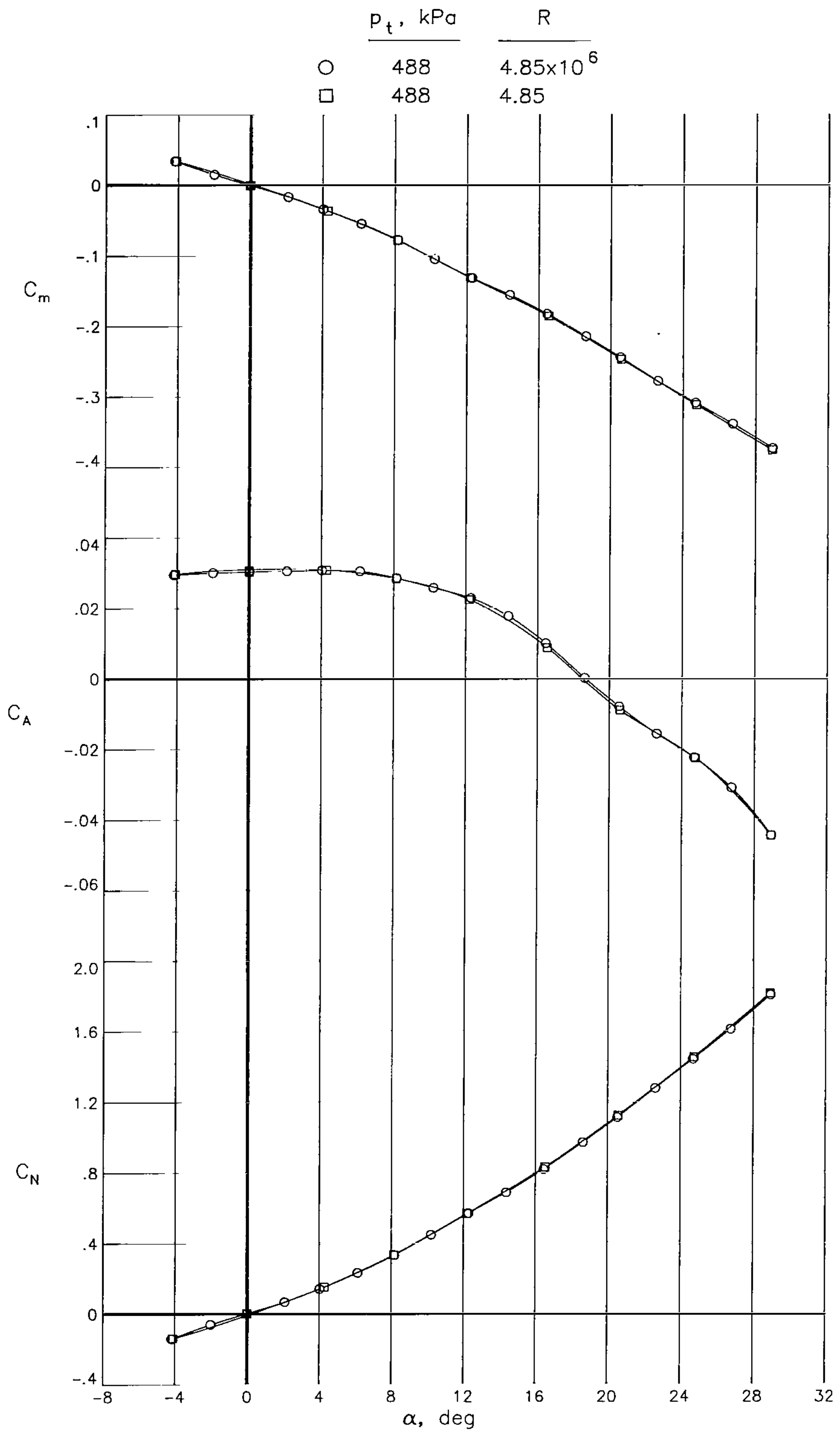


Figure 20.- Comparison of results for repeat runs for configuration 2 with balance heaters off at $M = 0.3$ and $T_t = 300$ K.

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16. Abstract

Aerodynamic force measurements on a generalized 75° delta-wing model with sharp leading edges have been made with a three-component internal strain-gage balance in a cryogenic wind tunnel at stagnation temperatures of 300 K, 200 K, and 110 K. The feasibility of using a strain-gage balance without thermal control in a cryogenic environment as well as the use of electrical resistance heaters, an insulator between the model and the balance, and a convection shield on the balance was investigated. Force and moment data on the delta-wing model as measured by the balance are compared at the different temperatures while holding constant either the Reynolds number or the tunnel stagnation pressure. Tests were made at Mach numbers of 0.3 and 0.5 and at angles of attack up to 29°. The results indicate that it is feasible to acquire accurate force and moment data while operating at steady-state thermal conditions in a cryogenic wind tunnel, either with or without electrical heaters on the balance. Within the limits of the balance accuracy, there were no apparent Reynolds number effects on the aerodynamic results for the delta-wing model.

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