NASA TECHNICAL MEMORANDUM

NASA TM X- 73924

NASA TM X- 73924

(NASA-TM-X-73924) AN ANALYSIS OF DATA RELATED TO THE MINIMUM TEMPERATURES FOR VALID TESTING IN CRYOGENIC WIND TUNNELS USING NITROGEN AS THE TEST GAS (NASA) 110 p HC $5.50 CSCL 14B G3/09

N76-29269

Unclas 48417

AN ANALYSIS OF DATA RELATED TO THE MINIMUM TEMPERATURES FOR VALID TESTING IN CRYOGENIC WIND TUNNELS USING NITROGEN AS THE TEST GAS

by Robert M. Hall

August 1976

This informal documentation medium is used to provide accelerated or special release of technical information to selected users. The contents may not meet NASA formal editing and publication standards, may be revised, or may be incorporated in another publication.

NASA
National Aeronautics and Space Administration

Langley Research Center
Hampton, Virginia 23665

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-73924		

4. Title and Subtitle	5. Report Date
AN ANALYSIS OF DATA RELATED TO THE MINIMUM TEMPERATURES FOR VALID TESTING IN CRYOGENIC WIND TUNNELS USING NITROGEN AS THE TEST GAS	August 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Robert M. Hall, NASA Langley Research Center	
9. Performing Organization Name and Address	10. Work Unit No.
NASA Langley Research Center Hampton, VA 23665	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Material will be combined with additional material and converted to a formal publication by July 1977.

16. Abstract

The minimum operating temperature which avoids adverse low-temperature effects, such as condensation, has been determined at a free-stream Mach number of 0.85 for flow over a 0.137-meter NACA 0012-64 airfoil mounted at zero incidence in the Langley 1/3-meter transonic cryogenic tunnel. The onset of low-temperature effects is established by comparing the pressure coefficient measured at a given orifice for a particular temperature with those measured at temperatures sufficiently above where low-temperature effects might be expected to occur. The pressure distributions over the airfoil are presented in tabular form. In addition, the comparisons of the pressure coefficient as a function of total temperature are presented graphically for chord locations of 0, 25, 50, and 75 percent. Over the 1.2 to 4.5 atmosphere total pressure range investigated, low-temperature effects are not detected until total temperatures are 2 K, or more, below free-stream saturation temperatures.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Cryogenic Wind Tunnels Minimum operating temperatures Low-temperature effects Pressure coefficient data Condensation	Unclassified-Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	109	$5.25

* For sale by the National Technical Information Service, Springfield, Virginia 22161

TM X-73924

AN ANALYSIS OF DATA RELATED TO THE MINIMUM TEMPERATURES FOR VALID TESTING IN CRYOGENIC WIND TUNNELS USING NITROGEN AS THE TEST GAS

Robert M. Hall

NASA Langley Research Center
Hampton, Virginia 23665

SUMMARY

The minimum operating temperature which avoids adverse low-temperature effects, such as condensation, has been determined at a free-stream Mach number of 0.85 for flow over a 0.137-meter NACA 0012-64 airfoil mounted at zero incidence in the Langley 1/3-meter transonic cryogenic tunnel. The onset of low-temperature effects is established by comparing the pressure coefficient measured at a given orifice for a particular temperature with those measured at temperatures sufficiently above where low-temperature effects might be expected to occur. The pressure distributions over the airfoil are presented in tabular form. In addition, the comparisons of the pressure coefficient as a function of total temperature are presented graphically for chord locations of 0, 25, 50, and 75 percent. Over the 1.2 to 4.5 atmosphere total pressure range investigated, low-temperature effects are not detected until total temperatures are 2 K, or more, below free-stream saturation temperatures.

INTRODUCTION

Cryogenic wind tunnels take advantage of the fact that at a given pressure and Mach number Reynolds number increases as the operating temperature decreases. However, at some low values of temperature, depending on tunnel pressure, the test gas ceases to properly simulate flow in ambient-temperature air because of low-temperature processes such as condensation. Accurate determination of the minimum operating temperatures for proper flow simulation is therefore very important in predicting the maximum Reynolds number capability of a cryogenic tunnel. An experimental program has been undertaken at the NASA Langley Research Center to determine the minimum operating temperatures for various conditions in cryogenic wind tunnels using nitrogen as the test gas. Both the Langley 1/3-meter transonic cryogenic tunnel and the National Transonic Facility currently under design utilize nitrogen as a test gas as explained in references 1 and 2, respectively. During 1974 and 1975 tests were performed in the Langley 1/3-meter transonic cryogenic tunnel to determine the temperature at which low-temperature effects are first seen in the pressure distribution over a 0.137-meter NACA 0012-64 airfoil being tested at a free-stream Mach number of 0.85.

During August, 1975, reference 3 was published to report on the progress of this program. From the preliminary analysis of the data, it was found that the pressure distributions over the airfoil are not altered by low-temperature effects until total temperatures were at least 2K below those associated with free-stream saturation. This result was observed over the 1.2 to 4.5 atmosphere total pressure range investigated. The airfoil pressure coefficient data used for the preliminary analysis were included in graphical form in the appendix of reference 3.

To permit more accurate analysis of the data originally presented in graphical form in reference 3, the present report presents the same airfoil data in tabular form. Furthermore, additional analysis of the data is described herein by plotting changes in the pressure coefficient at a given orifice as a function of total temperature and by taking into account the actual experimental uncertainty in the measured values of pressure coefficient. Although the present report does present a more systematic analysis than was included in reference 3, the reader is encouraged to refer to reference 3 for details of the original analysis.

SYMBOLS

c	airfoil chord, 0.137 meter
C_p	pressure coefficient, $\frac{p - p_\infty}{q_\infty}$
M	Mach number
p	pressure
q	dynamic pressure
R	Reynolds number based on a chord of 0.137 meter
T	temperature
x	linear dimension along airfoil chord line
γ	ratio of specific heats
σ	root mean square error

Subscripts:

L	local conditions
t	total conditions
∞	free-stream conditions

APPARATUS

Tunnel

The Langley 1/3-meter transonic cryogenic tunnel was used for these tests. A sketch of the tunnel is presented as figure 1. This continuous flow, fan-driven tunnel uses nitrogen as the test gas and is cooled by injecting liquid nitrogen directly into the stream. Injection of liquid nitrogen provides a total temperature range from slightly greater than 77 K to 350 K. Since the tunnel may also be pressurized to 5 atmospheres, the combined low temperature and high pressure can produce a Reynolds number near sonic speeds of over 328 million per meter (100 million per foot). Some of the design features and operational characteristics of the tunnel are given in reference 4.

Airfoil

A sketch of the 0.137 meter NACA 0012-64 airfoil used for these tests is presented as figure 2. As shown in figure 2, there are twenty pressure orifices over both the top and the bottom of the airfoil. The airfoil was installed between two opposite walls in the octagonal test section with the leading edge 0.62 meter from the beginning of the test section.

Data Acquisition

The pressures over the airfoil were measured by using a single 1.7 atmospheres differential pressure transducer and a scanning valve system. After the transducer output for all of the airfoil orifices was recorded, the tunnel parameters were recorded. The total time to acquire all the information for a complete pressure distribution was 50 seconds.

TESTS

Total temperatures at which condensation or other real-gas effects perturb the pressure distribution over the 0.137-meter NACA 0012-64 airfoil at zero incidence were determined for pressures from 1.2 to 4.5 atmospheres. The free-stream Mach number was 0.85 and the maximum local Mach number over the airfoil was 1.20.

Since Adcock in reference 5 found no significant real-gas deviations in the behavior of gaseous nitrogen for temperatures down to saturation values, the region in which to look for low-temperature effects could be confined to temperatures at or below those corresponding to saturated flow, which occurs first in the maximum local Mach number region over the airfoil. The temperature region to be investigated is therefore between the three stages of saturation- local, free-stream, and reservoir- as shown in figure 3 for the NACA 0012-64 airfoil. Six different paths of constant Reynolds numbers were used to examine the region and are shown in figure 4. Since both Reynolds number and Mach number were held constant along each path, any change in the pressure distribution was attributed to low-temperature effects. To avoid any possibility of condensation affecting the warmer distributions along each path, some pressure distributions were normally taken above the local saturation temperature. Along paths 5 and 6, however, a pressure distribution could not be taken above the local saturation temperature because of the tunnel pressure limit of 5 atmospheres.

ERROR ANALYSIS

The low-temperature effects observed for the current test conditions had only a small effect on the pressure distribution over the NACA 0012-64 airfoil. Because of the small magnitude of the effects seen, establishing the temperature at which these effects begin to occur requires careful consideration. In particular, it becomes important to be able to distinguish between the deviations in C_p caused by low-temperature effects and the random errors in C_p caused by instrumentation and by fluctuations in tunnel operating conditions. Consequently, as a means of estimating the random deviations in C_p, the root mean square (rms) error in C_p due to possible errors in instrumentation or tunnel conditions is calculated.

As a first step in determining the rms error in C_p, the instrumentation inaccuracies will be examined. For the pressure transducer used in recording the pressure distribution over the airfoil, the measurement accuracy, according to the manufacturer's specifications, is 0.5% of full scale reading, or 0.0085 atmospheres for the present test. However, most of the data show such accuracy and precision from data point to data point and from day to day that the value of 0.0085 atmospheres seems to be much too large. Furthermore, although the scatter in the data will be seen to correlate with the magnitude of fluctuations in tunnel conditions, it does not seem to correlate with a possible instrument error, which would produce equal scatter in all values of C_p for a given Mach number and total pressure. Consequently, the uncertainty, and hence rms error, in the pressure readings due to instrument accuracy is assumed to be negligible.

In addition to possible instrument error, the actual flow conditions in the tunnel fluctuate due to limitations in the various tunnel control systems. For example, Mach number was observed to fluctuate about a mean value by $\pm$ 0.003, which is used to approximate the rms error in Mach number. The frequency of this fluctuation was observed to be on the order of 2 seconds or less. The uncertainty in Mach number and other tunnel parameters due to instrument error will be considered negligible in comparison to the magnitude of the fluctuations due to the tunnel controls.

A slower fluctuation in tunnel conditions occurred with total pressure. During the 50 second data acqusition period, total pressure would normally begin to drift from the desired set point. The mean square value of this fluctuation was on the order of 0.010 atmosphere, depending on the path. The contribution of total pressure drift to the rms error in C_p has been calculated for the specific magnitude of drift observed along each path. The period of this drift in total pressure was much longer than for the drift in free-stream Mach number, typically 10 seconds or longer.

Tunnel total temperature also varied during the time required to obtain a given pressure distribution. The rms error in total temperature was approximately 0.5 K. The period of the variation in total temperature was again on the order of 10 seconds. Except for possible higher order effects due to changes in Reynolds number, a change in total temperature does not directly affect the pressure coefficient except as it may introduce uncertainty in the actual test conditions.

Using the above rms errors in tunnel conditions, one may calculate the combined rms error in C_p. This is done in the Appendix section of this paper. The results of the calculations are shown in the graphs to be presented in the Results section, where the uncertainty bars represent the calculated contributions to the rms error in C_p from total pressure fluctuations, Mach number fluctuations, and the combination of the two.

TABULATED DATA

The pressure coefficient distributions originally presented in graphical form in reference 3 are presented herein in tables and are numbered to correspond with the appropriate figure used in the appendix of reference 3. For example, the data presented graphically in appendix figure A10 in reference 3 is presented in this report in table 10. The reader may notice a difference in the last digit of some of the test-condition parameters, such as T_t or M_∞, between the tables and the figures. These differences are the result of number truncation in the computer routines used to generate the figures presented in reference 3. The numbers in the present report are therefore more accurate in the last digit. The data presented in reference 3 and herein were acquired on eight different days. The day on which a particular pressure distribution was taken is included in the tables.

The values of C_p given in the tables were calculated from the standard definition

$$C_p = \frac{p - p_\infty}{q_\infty}$$

where p is the static pressure measured at the orifice, p_∞ is the static pressure measured in the plenum, and q_∞ is the value of free-stream dynamic pressure, as calculated by using real-gas equations. A discussion of real-gas effects and real-gas equations is given by Adcock in reference 5. If there was a pressure tubing leak for a given orifice location, the value of C_p is replaced by astericks.

RESULTS

As a means of detecting changes in the pressure distributions along a particular path, plots are drawn showing the change in C_p at particular x/c locations as a function of total temperature. For each of the six paths investigated, graphs are made for x/c locations of 0.0, 0.25, 0.50 and 0.75. The change in C_p is plotted at each orifice by subtracting from C_p an average value of C_p calculated from the four warmest distributions taken along the path of constant Reynolds and Mach number. This average value is called CPAVE. Each graph shows the individual contributions to the predicted rms error in C_p due to the fluctuations in total pressure and Mach number as well as the resulting rms error in C_p due to both influences. The magnitudes of these error bars were calculated as explained in the section on error analysis. The possible error in CPAVE itself is on the order of the combined error in C_p divided by 2 since four samples went into the calculation. This possible error is not shown in the graphs. As the values of C_p - CPAVE are plotted as a function of total temperature, any value larger than the predicted rms error in C_p is plotted as a square symbol instead of a circular symbol.

The determination of the onset of low-temperature effects is challenging because of the rather small deviations observed in C_p and the resulting difficulty in separating low-temperature effects from scatter in C_p due to fluctuating tunnel conditions. Consequently, the approach taken in this report, as well as in reference 3, is to use two criteria for the determination of the onset of effects. The first criterion establishes onset at the first possible signs of systematic deviation in C_p at a given orifice, and thus disregards the magnitude of the error bar in the measurement. This first criterion is very conservative in nature and marks the onset of "possible" effects. The second criterion marks the onset of effects when the deviations in the value of C_p are equal to or greater than the predicted rms error in the measurement. This second criterion is not as conservative as the first and establishes the onset of more "definite" effects. A realistic minimum operating boundary would, perhaps, lie somewhere between the onset temperatures established by the two criteria. A brief summary of results will now be given for each path of constant Reynolds number.

Path 1, R=15.6 Million

The plots of C_p - CPAVE for x/c values of 0.0, 0.25, 0.50, and 0.75 are shown in figures 5 to 8. Because of the low total pressures along this path, the predicted rms error due to total pressure fluctuations is relatively large. Nevertheless, consistent deviations larger than the combined error in C_p begin to occur at a total temperature of 84.2 K for the x/c value of 0.25. This temperature will be considered as showing "definite" effects. The first signs of any systematic effects occur at a temperature of 85.2 K at x/c values of 0.25 and 0.50. Thus 85.2 K will be considered as the beginning of "possible effects."

Path 2, R=25.9 Million

The plots of C_p - CPAVE for x/c values of 0.0, 0.25, 0.50, and 0.75 are shown in figures 9 to 12. The warmest temperature where C_p - CPAVE is larger than the combined rms error occurs at a total temperature of 88.6 K for x/c positions of 0.25, 0.50, and 0.75. This temperature will be considered the onset of "definite" low-temperature effects. The first signs of any "possible" variation in the value of C_p - CPAVE may be occurring at 91.3 K for the x/c value of 0.50.

Path 3, R=34.0 Million

The plots of C_p - CPAVE for x/c values of 0.0, 0.25, 0.50, and 0.75 are shown in figures 13 to 16. "Definite" effects begin to first occur at a total temperature of 93.0 K for x/c locations of 0.25 and 0.50. The first signs of "possible" effects do not seem to develop before the 93.0 K total temperature, so "possible" effects will also be considered to begin at 93.0 K.

As will be developed more completely under the description for path 4 results, test data taken on the fourth day of testing do not always seem to correlate with the data taken on the other days. Although the two data points taken on the fourth day along this path do not seem out of place, the graphs are repeated in figures 17 to 20 without the day 4 data. Very little difference in results is obtained for this case. Now both "definite" and "possible" deviations occur at a total temperature of 92.7 K instead of 93.0 K.

Path 4, R=38.1 Million

The plots of C_p - CPAVE for x/c values of 0.0, 0.25, 0.50, and 0.75 are shown in figures 21 to 24. The warmest temperature where C_p - CPAVE is greater than the predicted rms error occurs at an x/c value of 0.0 and at a total temperature of 97.1 K. This point, however, will not be used to designate the onset of "definite" effects because of a suspected error in CPAVE. A more positive value of CPAVE would, of course, shift C_p - CPAVE so that the large positive deviation at 97.1 K is actually within the expected scatter. Although the repeatability of the tunnel conditions is normally so reliable that it is standard procedure to compare data taken on different days, there seems to be a consistent problem in paths 4, 5, and 6 with data taken on the fourth day of testing. For path 4, the three warmest pressure distributions along this path were taken during the second day of testing while the seven lower temperature distributions were taken on the fourth day of running. The author believes there may have been a problem with tunnel instrumentation or tunnel controllability on the fourth day. That there is no apparent problem along path 3 with the day 4 data seems to imply that the difficulty was not as severe at the lower total pressures. The simplest solution is to handle the fourth day data independent of the rest of the data. In the present case this suggests dropping the three warmest distributions from the graphs.

A new set of plots of C_p - CPAVE for x/c values of 0.0, 0.25, 0.50, and 0.75 is shown in figures 25 to 28. These plots include only the data from the fourth day. It does compromise the data base somewhat not to include the warmer distributions which would be unmistakenly without condensation effects. Nevertheless, since effects in the earlier paths occurred below free-stream saturation, it seems reasonable that the two remaining pressure distributions warmer than free-stream saturation should provide a basis for proper comparison. Using the new set of plots, the first signs of "definite" effects occur at an x/c location of 0.0 and a total temperature of 93.9 K. The first signs of "possible" effects are most clearly seen at a total temperature of 95.4 K for x/c values of 0.25 and 0.50.

More data would need to be taken along path 4 in order to be certain that the present temperatures for "definite" and "possible" effects are accurate.

Path 5, R=42.1 Million

The plots of C_p - CPAVE for x/c values of 0.0, 0.25, 0.50, and 0.75 are shown in figures 29 to 32. The first signs of effects appear in the x/c=0.75 graph. There are three values of C_p - CPAVE which give positive deviations which are outside of the rms error in C_p. However, these three values, and only these three values, were taken on the fourth day of testing. Consequently, these deviations appear to be a further manifestation of some type of systematic error that existed during the fourth day of testing. Along this path the three distributions in question can be dropped without affecting either the warmer values used for calculating CPAVE or the colder distributions.

The plots of C_p - CPAVE without the data obtained on the fourth day of testing are shown in figures 33 to 36. Deviations larger than the combined rms error first occur at a total temperature of 95.5 K for x/c values of 0.0 and 0.75. This marks the beginning of "definite" effects. "Possible" effects are first seen for 95.6 K at an x/c location of 0.0.

Path 6, R=44.8 Million

The plots of C_p - CPAVE for x/c values of 0.0, 0.25, 0.50, and 0.75 are shown in figures 37 to 40. The same irregularity in the $x/c = 0.75$ graph is seen in figure 40 as was seen in figure 32 of path 5. Again the two C_p - CPAVE values which show deviations larger than the predicted rms error in the positive direction were the only two data points along this path that were taken on the fourth day of testing.

The graphs without the data from the fourth day are given in figures 41 to 44. The first sign of "possible" effects are seen at a total temperature of 96.2 K for x/c values of 0.0, 0.25, and 0.75. "Definite" effects are first seen at 96.2 K for an x/c value of 0.25.

DISCUSSION

The total conditions where the present method detected either "possible" or "definite" effects can be summarized by plotting the onset temperature for each constant Reynolds number path on a graph showing the three stages of saturation -- local, free-stream, and reservoir. "Possible" effects as calculated by the present analysis are plotted in figure 45. Not only is it possible to operate below local saturation over the airfoil without low-temperature effects, but it is not until about 2 K below free-stream saturation that effects are first seen. The onset of "possible" effects as calculated from reference 3 are also shown for comparison. For paths 1 and 2 the present detection procedure gives a slightly earlier indication of effects.

"Definite" effects as calculated by the present analysis are shown in figure 46. These points fall, of course, at or below the

the onset of "possible" effects. For comparison purposes, the points corresponding to the beginning of "definite" effects from reference 3 are also shown. Throughout the pressure range the present technique is more sensitive to low-temperature effects. In addition, because the present report utilized error bars in order to fix when the deviations were to be considered "definite," the decision to call deviations "definite" could be made more quantitatively than in reference 3. It is worthwhile to note that with the present more quantitative technique the onset of "definite" effects occurs at a nearly constant temperature difference below free-stream saturation, in contrast to the results of reference 3.

As was mentioned earlier in this report, a practical lower total temperature boundary might actually lie below the line of "possible" effects. The criterion for determining the beginning of "possible" effects was very strict, and may, indeed, be more rigorous than required for normal wind-tunnel testing. Of course, if an experimentalist does not want to tolerate the slightest possible effect, he may want to stay above the line of "possible" effects. It should be emphasized, however, that the present results were obtained for a 0.137-meter NACA 0012-64 airfoil set at a zero angle of attack and tested at a nominal free-stream Mach number of 0.85. Different types and sizes of airfoils will have to be tested before the results can be generalized.

SUMMARY OF RESULTS

The minimum operating temperature which avoids adverse low-temperature effects, such as condensation, has been determined at a free-stream Mach number of 0.85 for flow over a 0.137-meter NACA 0012-64 airfoil mounted at zero incidence in the Langley 1/3-meter transonic cryogenic tunnel. The onset of low-temperature effects is established by comparing the pressure coefficient measured at a given orifice for a particular temperature with those measured at temperatures sufficiently above where low-temperature effects might be expected to occur. The pressure distributions over the airfoil are presented in tabular form. In addition, the comparisons of the pressure coefficient as a function of total temperature are presented graphically for chord locations of 0, 25, 50, and 75 percent. Over the 1.2 to 4.5 atmosphere total pressure range investigated, low-temperature effects are not detected until total temperatures are 2 K, or more, below free-stream saturation temperatures.

APPENDIX

CALCULATING THE ROOT MEAN SQUARE ERROR IN C_p

By definition the coefficient of pressure is defined as

$$C_p = \frac{p - p_\infty}{q_\infty} \tag{A1}$$

where p, p_∞, q_∞ can be represented as

$$p = f_1 \left(\frac{x}{c}, p_t, M_\infty\right) \tag{A2}$$

$$p_\infty = f_2 (p_t, M_\infty) \tag{A3}$$

$$q_\infty = f_3 (p_t, M_\infty) \tag{A4}$$

The function f_1 can be estimated either theoretically or experimentally while functions f_2 and f_3 are taken from the equations for one-dimensional flow. As mentioned in the main text, instrument accuracy does not affect C_p as greatly as fluctuations in the tunnel parameters. Consequently, in determining the rms error in C_p, only the contributions from fluctuations in total pressure and Mach number are considered. Denoting root mean square error by σ,

$$\sigma_{C_p}^2 = \left(\frac{\partial C_p}{\partial p_t}\right)^2 \sigma_{p_t}^2 + \left(\frac{\partial C_p}{\partial M_\infty}\right)^2 \sigma_{M_\infty}^2 \tag{A5}$$

The next two sections describe the calculations of the partial derivatives.

Calculating $\left.\frac{\partial C_p}{\partial p_t}\right|_{M_\infty}$

The total pressure of the tunnel fluctuates during the operation of the tunnel and perturbs the value of pressure at a particular orifice. The difference in the value of pressure at an x/c location on the airfoil will change the calculated value of C_p, which may be written as

$$C_p = \frac{\frac{p}{p_t} - \frac{p_\infty}{p_t}}{\frac{q_\infty}{p_t}} \tag{A6}$$

Since M_∞ is assumed to be constant

$$\frac{p_\infty}{p_t} = K_1 \tag{A7}$$

and

$$\frac{q_\infty}{p_t} = K_2 \tag{A8}$$

where K_1 and K_2 are constants. We may now write C_p as

$$C_p = \frac{\frac{p}{p_t} - K_1}{K_2} \tag{A9}$$

Differentiating with respect to total pressure,

$$\left.\frac{\partial C_p}{\partial p_t}\right|_{M_\infty} = \frac{1}{K_2}\left(-\frac{p}{p_t^{\,2}}\right) \tag{A10}$$

or

$$\left.\frac{\partial C_p}{\partial p_t}\right|_{M_\infty} = -\frac{p}{q_\infty p_t} \tag{A11}$$

Calculating $\left.\frac{\partial C_p}{\partial M_\infty}\right|_{p_t,\ \frac{x}{c}}$

This case is more complicated than the previous one because the functional form of f_1 is not known explicitly. Nevertheless, using the functional definitions given in equations (A2) to (A4), one may write

$$\left.\frac{\partial C_p}{\partial M_\infty}\right|_{p_t, \frac{x}{c}} = \frac{\left(\frac{\partial f_1}{\partial M_\infty} - \frac{\partial f_2}{\partial M_\infty}\right) f_3 - (f_1 - f_2) \frac{\partial f_3}{\partial M_\infty}}{f_3^{\,2}} \tag{A12}$$

Assuming ideal, one-dimensional equations with $\gamma = 1.4$, one may also write

$$f_2 \, (p_t, M_\infty) = p_t \left(1 + \frac{M_\infty^{\,2}}{5}\right)^{-3.5} \tag{A13}$$

$$f_3 \, (p_t, M_\infty) = p_t \, (.7 \, M_\infty^{\,2}) \left(1 + \frac{M_\infty^{\,2}}{5}\right)^{-3.5} \tag{A14}$$

Consequently,

$$\left.\frac{\partial f_2}{\partial M_\infty}\right|_{p_t} = -1.4 \, p_t \, M_\infty \left(1 + \frac{M_\infty^{\,2}}{5}\right)^{-4.5} \tag{A15}$$

$$\left.\frac{\partial f_3}{\partial M_\infty}\right|_{p_t} = 1.4 \, p_t \, M_\infty \left(1 + \frac{M_\infty^{\,2}}{5}\right)^{-4.5} \left(1 - \frac{M_\infty^{\,2}}{2}\right) \tag{A16}$$

After conducting experiments in the 1/3-meter wind tunnel that varied Mach number about $M_\infty = 0.85$, it has been found that the f_1

derivatives can be roughly estimated to be

$$\left.\frac{\partial f_1}{\partial M_\infty}\right|_{p_t,\ \frac{x}{c} = 0} = -.2 \tag{A17}$$

$$\left.\frac{\partial f_1}{\partial M_\infty}\right|_{p_t,\ \frac{x}{c} = .25} = -.7 \tag{A18}$$

$$\left.\frac{\partial f_1}{\partial M_\infty}\right|_{p_t,\ \frac{x}{c} = .50} = -.8 \tag{A19}$$

$$\left.\frac{\partial f_1}{\partial M_\infty}\right|_{p_t,\ \frac{x}{c} = .75} = -.2 \tag{A20}$$

Equations (A15), (A16), and (A17) to (A20) can then be substituted into equation (A12) to determine $\left.\frac{\partial C_p}{\partial M_\infty}\right|_{p_t,\ \frac{x}{c}}$.

Once $\frac{\partial C_p}{\partial p_t}$ and $\frac{\partial C_p}{\partial M_\infty}$ have been calculated, equation (A5) can be used to predict the rms error in the value of C_p. The calculated values of rms error are shown in figures 5 to 44, as well as the individual contributions to the error from the total pressure and Mach number fluctuations.

REFERENCES

1. Ray, Edward J.; Kilgore, Robert A.; Adcock, Jerry B.; and Davenport, Edwin E.: Analysis of Validation Tests of the Langley Pilot Transonic Cryogenic Tunnel. AIAA Journal of Aircraft, vol. 12, no. 6, June 1975, pp 539 - 544.

2. McKinney, Linwood W.; and Howell, Robert R.: The Characteristics of the Planned National Transonic Facility. Presented at the AIAA Ninth Aerodynamic Testing Conference, Arlington, Texas, June 7-9, 1976.

3. Hall, Robert M.: Preliminary Study of the Minimum Temperatures for Valid Testing in a Cryogenic Wind Tunnel. NASA TM X-72700, 1975.

4. Kilgore, Robert A.: Design Features and Operational Characteristics of the Langley Pilot Transonic Cryogenic Tunnel. NASA TM X-72012, 1974.

5. Adcock, Jerry B.; Kilgore, Robert A.; and Ray, Edward J.: Cryogenic Nitrogen as a Transonic Wind-Tunnel Test Gas. AIAA Paper No. 75-143, Jan 1975.

PRECEDING PAGE BLANK NOT FILMED

TABLE 1. - PATH 1.

TOTAL TEMPERATURE = 116.3 K
TOTAL PRESSURE = 2.12 ATM
MACH INFINITY = .847
CHORD REYNOLDS NUMBER = 15.5 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1953	.50	-.5950
.05	-.0865	.55	-.6215
.10	-.2795	.60	-.6604
.15	-.3417	.65	-.2850
.20	-.3699	.70	-.1717
.25	-.3688	.75	-.1169
.30	-.4184	.80	-.0540
.35	-.4829	.85	.0176
.40	-.5179	.90	.1094
.45	-.5503	.95	.2118

TABLE 2. - PATH 1.

TOTAL TEMPERATURE = 114.8 K
TOTAL PRESSURE = 2.11 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 15.8 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.1983	.50	-.5953
.05	-.0774	.55	-.6203
.10	-.2626	.60	-.6652
.15	-.3564	.65	-.3867
.20	-.3806	.70	-.1658
.25	-.3698	.75	-.1022
.30	-.4092	.80	-.0417
.35	-.4739	.85	.0270
.40	-.5156	.90	.1163
.45	-.5464	.95	.2167

TABLE 3. - PATH 1.

TOTAL TEMPERATURE = 114.3 K
TOTAL PRESSURE = 2.10 ATM
MACH INFINITY = .859
CHORD REYNOLDS NUMBER = 15.8 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2061	.50	-.5957
.05	-.0764	.55	-.6222
.10	-.2652	.60	-.6686
.15	-.3568	.65	-.5574
.20	-.3842	.70	-.1790
.25	-.3697	.75	-.0942
.30	-.4087	.80	-.0327
.35	-.4715	.85	.0303
.40	-.5075	.90	.1191
.45	-.5486	.95	.2166

TABLE 4. - PATH 1.

TOTAL TEMPERATURE = 105.4 K
TOTAL PRESSURE = 1.85 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 15.7 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.2028	.50	-.5980
.05	-.0796	.55	-.6244
.10	-.2686	.60	-.6727
.15	-.3618	.65	-.4107
.20	-.3852	.70	-.1744
.25	-.3731	.75	-.1011
.30	-.4113	.80	-.0400
.35	-.4740	.85	.0245
.40	-.5094	.90	.1134
.45	-.5488	.95	.2174

TABLE 5. - PATH 1.

TOTAL TEMPERATURE = 100.4 K
TOTAL PRESSURE = 1.74 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 15.8 MILLION

DISTRIBUTION TAKEN ON DAY 8 OF TESTING

X/C	CP	X/C	CP
.00	1.1951	.50	-.5908
.05	-.0776	.55	-.6208
.10	-.2660	.60	-.6677
.15	-.3560	.65	-.3710
.20	-.3710	.70	-.1646
.25	-.3724	.75	-.0989
.30	-.4105	.80	-.0407
.35	-.4644	.85	.0254
.40	-.5095	.90	.1116
.45	-.0024	.95	.2132

TABLE 6. - PATH 1.

TOTAL TEMPERATURE = 95.0 K
TOTAL PRESSURE = 1.59 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 15.7 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1941	.50	-.5909
.05	-.0761	.55	-.6178
.10	-.2650	.60	-.6566
.15	-.3514	.65	-.3796
.20	-.3803	.70	-.1644
.25	-.3665	.75	-.1008
.30	-.4069	.80	-.0416
.35	-.4677	.85	.0234
.40	-.5076	.90	.1144
.45	-.5416	.95	.2136

TABLE 7. - PATH 1.

TOTAL TEMPERATURE = 91.3 K
TOTAL PRESSURE = 1.49 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 15.6 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.2077	.50	-.5996
.05	-.0813	.55	-.6219
.10	-.2713	.60	-.6627
.15	-.3553	.65	-.3142
.20	-.3830	.70	-.1670
.25	-.3705	.75	-.1069
.30	-.4130	.80	-.0464
.35	-.4769	.85	.0205
.40	-.5197	.90	.1145
.45	-.5507	.95	.2139

TABLE 8. - PATH 1.

TOTAL TEMPERATURE = 87.4 K
TOTAL PRESSURE = 1.39 ATM
MACH INFINITY = .853
CHORD REYNOLDS NUMBER = 15.5 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.2080	.50	-.5985
.05	-.0848	.55	-.6241
.10	-.2748	.60	-.6663
.15	-.3585	.65	-.3691
.20	-.3830	.70	-.1716
.25	-.3724	.75	-.1058
.30	-.4165	.80	-.0458
.35	-.4805	.85	.0206
.40	-.5191	.90	.1114
.45	-.5515	.95	.2101

TABLE 9. - PATH 1.

TOTAL TEMPERATURE = 86.5 K
TOTAL PRESSURE = 1.37 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 15.5 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2107	.50	-.5986
.05	-.0766	.55	-.6269
.10	-.2636	.60	-.6787
.15	-.3575	.65	-.5683
.20	-.3854	.70	-.1736
.25	-.3710	.75	-.1004
.30	-.4138	.80	-.0435
.35	-.4738	.85	.0279
.40	-.5169	.90	.1197
.45	-.5501	.95	.2176

TABLE 10. - PATH 1.

TOTAL TEMPERATURE = 85.3 K
TOTAL PRESSURE = 1.35 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 15.5 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1928	.50	-.5884
.05	-.0769	.55	-.6154
.10	-.2621	.60	-.6674
.15	-.3519	.65	-.5290
.20	-.3786	.70	-.1748
.25	-.3657	.75	-.0962
.30	-.4047	.80	-.0393
.35	-.4665	.85	.0279
.40	-.5051	.90	.1159
.45	-.5420	.95	.2155

TABLE 11. - PATH 1.

TOTAL TEMPERATURE = 84.2 K
TOTAL PRESSURE = 1.31 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 15.4 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.1919	.50	-.5882
.05	-.0763	.55	-.6161
.10	-.2586	.60	-.6633
.15	-.3521	.65	-.4610
.20	-.3741	.70	-.1725
.25	-.3618	.75	-.0977
.30	-.4028	.80	-.0396
.35	-.4664	.85	.0248
.40	-.5042	.90	.1137
.45	-.5404	.95	.2143

TABLE 12. - PATH 1.

TOTAL TEMPERATURE = 83.8 K
TOTAL PRESSURE = 1.30 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 15.4 MILLION

DISTRIBUTION TAKEN ON DAY 3 OF TESTING

X/C	CP	X/C	CP
.00	1.1949	.50	-.5834
.05	-.0755	.55	-.6090
.10	-.2602	.60	-.6547
.15	-.3429	.65	-.4319
.20	-.3695	.70	-.1735
.25	-.3569	.75	-.1085
.30	-.4044	.80	-.0434
.35	-.4710	.85	.0181
.40	-.5015	.90	.1108
.45	-.5351	.95	.2106

TABLE 13. - PATH 1.

TOTAL TEMPERATURE = 83.3 K
TOTAL PRESSURE = 1.29 ATM
MACH INFINITY = .853
CHORD REYNOLDS NUMBER = 15.4 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1889	.50	-.5852
.05	-.0804	.55	-.6085
.10	-.2676	.60	-.6538
.15	-.3347	.65	-.3106
.20	-.3661	.70	-.1683
.25	-.3595	.75	-.1110
.30	-.4083	.80	-.0480
.35	-.4730	.85	.0159
.40	-.5067	.90	.1094
.45	-.5395	.95	.2105

TABLE 14. - PATH 1.

TOTAL TEMPERATURE = 82.6 K
TOTAL PRESSURE = 1.27 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 15.3 MILLION

DISTRIBUTION TAKEN ON DAY 8 OF TESTING

X/C	CP	X/C	CP
.00	1.1936	.50	-.5789
.05	-.0770	.55	-.6087
.10	-.2601	.60	-.6520
.15	-.3322	.65	-.3813
.20	-.3473	.70	-.1652
.25	-.3551	.75	-.1114
.30	-.4079	.80	-.0506
.35	-.4597	.85	.0178
.40	-.5013	.90	.1075
.45	-.0028	.95	.2077

TABLE 15. - PATH 1.

TOTAL TEMPERATURE = 81.4 K
TOTAL PRESSURE = 1.20 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 14.8 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1761	.50	-.5723
.05	-.0773	.55	-.5967
.10	-.2621	.60	-.6397
.15	-.3430	.65	-.2717
.20	-.3689	.70	-.1771
.25	-.3582	.75	-.1194
.30	-.4066	.80	-.0585
.35	-.4655	.85	.0102
.40	-.4954	.90	.1037
.45	-.5283	.95	.2037

TABLE 16. - PATH 2.

TOTAL TEMPERATURE = 107.3 K
TOTAL PRESSURE = 3.17 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 26.2 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.1992	.50	-.6000
.05	-.0811	.55	-.6258
.10	-.2624	.60	-.6736
.15	-.3567	.65	-.5295
.20	-.3792	.70	-.1628
.25	-.3678	.75	-.0932
.30	-.4086	.80	-.0376
.35	-.4717	.85	.0304
.40	-.5130	.90	.1175
.45	-.5475	.95	.2220

TABLE 17. - PATH 2.

TOTAL TEMPERATURE = 101.8 K
TOTAL PRESSURE = 2.92 ATM
MACH INFINITY = .859
CHORD REYNOLDS NUMBER = 26.1 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2071	.50	-.5973
.05	-.0798	.55	-.6171
.10	-.2664	.60	-.6679
.15	-.3652	.65	-.3769
.20	-.3840	.70	-.1510
.25	-.3716	.75	-.1020
.30	-.4060	.80	-.0356
.35	-.4727	.85	.0277
.40	-.5111	.90	.1178
.45	-.5480	.95	.2208

TABLE 18. - PATH 2.

TOTAL TEMPERATURE = 98.8 K
TOTAL PRESSURE = 2.79 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 26.1 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2098	.50	-.5966
.05	-.0791	.55	-.6174
.10	-.2640	.60	-.6686
.15	-.3663	.65	-.3940
.20	-.3828	.70	-.1519
.25	-.3709	.75	-.0962
.30	-.4058	.80	-.0400
.35	-.4730	.85	.0264
.40	-.5118	.90	.1173
.45	-.5469	.95	.2198

TABLE 19. - PATH 2.

TOTAL TEMPERATURE = 95.9 K
TOTAL PRESSURE = 2.67 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 26.1 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2102	.50	-.5976
.05	-.0818	.55	-.6190
.10	-.2666	.60	-.6708
.15	-.3625	.65	-.3649
.20	-.3836	.70	-.1536
.25	-.3711	.75	-.1003
.30	-.4082	.80	-.0387
.35	-.4709	.85	.0245
.40	-.5119	.90	.1156
.45	-.5490	.95	.2198

TABLE 20. - PATH 2.

TOTAL TEMPERATURE = 94.3 K
TOTAL PRESSURE = 2.57 ATM
MACH INFINITY = .854
CHORD REYNOLDS NUMBER = 25.7 MILLION

DISTRIBUTION TAKEN ON DAY 3 OF TESTING

X/C	CP	X/C	CP
.00	1.1986	.50	-.6000
.05	-.0854	.55	-.6240
.10	-.2676	.60	-.6673
.15	-.3650	.65	-.4379
.20	-.3797	.70	-.1583
.25	-.3687	.75	-.0997
.30	-.4093	.80	-.0401
.35	-.4751	.85	.0298
.40	-.5114	.90	.1199
.45	-.5470	.95	.2228

TABLE 21. - PATH 2.

TOTAL TEMPERATURE = 93.0 K
TOTAL PRESSURE = 2.52 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 25.7 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2032	.50	-.5982
.05	-.0811	.55	-.6202
.10	-.2658	.60	-.6696
.15	-.3619	.65	-.4755
.20	-.3793	.70	-.1566
.25	-.3693	.75	-.1021
.30	-.4076	.80	-.0399
.35	-.4704	.85	.0276
.40	-.5130	.90	.1168
.45	-.5476	.95	.2190

TABLE 22. - PATH 2.

TOTAL TEMPERATURE = 91.9 K
TOTAL PRESSURE = 2.49 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 25.8 MILLION

DISTRIBUTION TAKEN ON DAY 3 OF TESTING

X/C	CP	X/C	CP
.00	1.2001	.50	-.5970
.05	-.0820	.55	-.6216
.10	-.2630	.60	-.6679
.15	-.3655	.65	-.5531
.20	-.3819	.70	-.1608
.25	-.3712	.75	-.0952
.30	-.4084	.80	-.0362
.35	-.4723	.85	.0276
.40	-.5092	.90	.1185
.45	-.5434	.95	.2181

TABLE 23. - PATH 2.

TOTAL TEMPERATURE = 91.7 K
TOTAL PRESSURE = 2.48 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 25.9 MILLION

DISTRIBUTION TAKEN ON DAY 3 OF TESTING

X/C	CP	X/C	CP
.00	1.2025	.50	-.5994
.05	-.0849	.55	-.6216
.10	-.2685	.60	-.6684
.15	-.3640	.65	-.4512
.20	-.3819	.70	-.1559
.25	-.3707	.75	-.0966
.30	-.4108	.80	-.0366
.35	-.4742	.85	.0269
.40	-.5133	.90	.1171
.45	-.5482	.95	.2198

TABLE 24. - PATH 2.

TOTAL TEMPERATURE = 91.4 K
TOTAL PRESSURE = 2.45 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 25.6 MILLION

DISTRIBUTION TAKEN ON DAY 3 OF TESTING

X/C	CP	X/C	CP
.00	1.2051	.50	-.5942
.05	-.0793	.55	-.6182
.10	-.2644	.60	-.6633
.15	-.3639	.65	-.4160
.20	-.3811	.70	-.1575
.25	-.3695	.75	-.1041
.30	-.4101	.80	-.0442
.35	-.4699	.85	.0220
.40	-.5119	.90	.1141
.45	-.5425	.95	.2173

TABLE 25. - PATH 2.

TOTAL TEMPERATURE = 90.1 K
TOTAL PRESSURE = 2.41 ATM
MACH INFINITY = .859
CHORD REYNOLDS NUMBER = 25.8 MILLION

DISTRIBUTION TAKEN ON DAY 3 OF TESTING

X/C	CP	X/C	CP
.00	1.2115	.50	-.5932
.05	-.0789	.55	-.6131
.10	-.2598	.60	-.6616
.15	-.3616	.65	-.4688
.20	-.3781	.70	-.1645
.25	-.3687	.75	-.0992
.30	-.4047	.80	-.0402
.35	-.4655	.85	.0267
.40	-.5099	.90	.1183
.45	-.5376	.95	.2193

TABLE 26. - PATH 2.

TOTAL TEMPERATURE = 89.8 K
TOTAL PRESSURE = 2.40 ATM
MACH INFINITY = .854
CHORD REYNOLDS NUMBER = 25.8 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2122	.50	-.5911
.05	-.0802	.55	-.6159
.10	-.2618	.60	-.6630
.15	-.3510	.65	-.4510
.20	-.3745	.70	-.1583
.25	-.3662	.75	-.1010
.30	-.4033	.80	-.0405
.35	-.4682	.85	.0246
.40	-.5126	.90	.1163
.45	-.5456	.95	.2182

TABLE 27. - PATH 2.

TOTAL TEMPERATURE = 88.7 K
TOTAL PRESSURE = 2.33 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 25.5 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2034	.50	-.5847
.05	-.0778	.55	-.6083
.10	-.2608	.60	-.6557
.15	-.3415	.65	-.4017
.20	-.3649	.70	-.1581
.25	-.3579	.75	-.1136
.30	-.4025	.80	-.0522
.35	-.4646	.85	.0145
.40	-.5078	.90	.1063
.45	-.5376	.95	.2123

TABLE 28. - PATH 2.

TOTAL TEMPERATURE = 86.2 K
TOTAL PRESSURE = 2.20 ATM
MACH INFINITY = .854
CHORD REYNOLDS NUMBER = 25.0 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.1797	.50	-.5772
.05	-.0769	.55	-.6033
.10	-.2636	.60	-.6488
.15	-.3253	.65	-.2966
.20	-.3507	.70	-.1628
.25	-.3527	.75	-.1107
.30	-.4045	.80	-.0518
.35	-.4648	.85	.0165
.40	-.5014	.90	.1078
.45	-.5332	.95	.2103

TABLE 29. - PATH 3.

TOTAL TEMPERATURE = 109.2 K
TOTAL PRESSURE = 4.29 ATM
MACH INFINITY = .862
CHORD REYNOLDS NUMBER = 34.7 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.1987	.50	-.5894
.05	-.0764	.55	-.6209
.10	-.2585	.60	-.6725
.15	-.3746	.65	-.5811
.20	-.3817	.70	-.1736
.25	-.3733	.75	-.0821
.30	-.4139	.80	-.0254
.35	-.4728	.85	.0361
.40	-.5111	.90	.1214
.45	-.5427	.95	.2221

TABLE 30. - PATH 3.

TOTAL TEMPERATURE = 109.5 K
TOTAL PRESSURE = 4.29 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 34.4 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1993	.50	-.5921
.05	-.0811	.55	-.6214
.10	-.2592	.60	-.6744
.15	-.3729	.65	-.6610
.20	-.3799	.70	-.1791
.25	-.3725	.75	-.0849
.30	-.4105	.80	-.0265
.35	-.4715	.85	.0348
.40	-.5133	.90	.1239
.45	-.5410	.95	.2213

TABLE 31. - PATH 3.

TOTAL TEMPERATURE = 106.5 K
TOTAL PRESSURE = 4.12 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 34.4 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1954	.50	-.5948
.05	-.0838	.55	-.6202
.10	-.2623	.60	-.6748
.15	-.3720	.65	-.6030
.20	-.3836	.70	-.1606
.25	-.3750	.75	-.0876
.30	-.4099	.80	-.0306
.35	-.4718	.85	.0317
.40	-.5097	.90	.1233
.45	-.5382	.95	.2232

TABLE 32. - PATH 3.

TOTAL TEMPERATURE = 102.3 K
TOTAL PRESSURE = 3.84 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 34.2 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2018	.50	-.5946
.05	-.0795	.55	-.6217
.10	-.2602	.60	-.6740
.15	-.3703	.65	-.6493
.20	-.3827	.70	-.1786
.25	-.3750	.75	-.0851
.30	-.4070	.80	-.0270
.35	-.4737	.85	.0362
.40	-.5103	.90	.1210
.45	-.5396	.95	.2234

TABLE 33. - PATH 3.

TOTAL TEMPERATURE = 100.5 K
TOTAL PRESSURE = 3.75 ATM
MACH INFINITY = .861
CHORD REYNOLDS NUMBER = 34.4 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1968	.50	-.5905
.05	-.0809	.55	-.6180
.10	-.2628	.60	-.6709
.15	-.3723	.65	-.6497
.20	-.3803	.70	-.1678
.25	-.3685	.75	-.0828
.30	-.4057	.80	-.0247
.35	-.4709	.85	.0390
.40	-.5075	.90	.1269
.45	-.5350	.95	.2244

TABLE 34. - PATH 3.

TOTAL TEMPERATURE = 97.4 K
TOTAL PRESSURE = 3.58 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 34.2 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1932	.50	-.5957
.05	-.0798	.55	-.6212
.10	-.2602	.60	-.6663
.15	-.3707	.65	-.5572
.20	-.3812	.70	-.1634
.25	-.3698	.75	-.0886
.30	-.4041	.80	-.0310
.35	-.4682	.85	.0309
.40	-.5079	.90	.1214
.45	-.5401	.95	.2225

TABLE 35. - PATH 3.

TOTAL TEMPERATURE = 94.9 K
TOTAL PRESSURE = 3.41 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 33.9 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1993	.50	-.5963
.05	-.0777	.55	-.6223
.10	-.2620	.60	-.6712
.15	-.3705	.65	-.5968
.20	-.3822	.70	-.1615
.25	-.3715	.75	-.0847
.30	-.4074	.80	-.0283
.35	-.4720	.85	.0351
.40	-.5091	.90	.1217
.45	-.5440	.95	.2235

TABLE 36. - PATH 3.

TOTAL TEMPERATURE = 94.5 K
TOTAL PRESSURE = 3.41 ATM
MACH INFINITY = .863
CHORD REYNOLDS NUMBER = 34.2 MILLION

DISTRIBUTION TAKEN ON DAY 1 OF TESTING

X/C	CP	X/C	CP
.00	1.1983	.50	-.5891
.05	-.0763	.55	-.6174
.10	-.2552	.60	-.6695
.15	-.3709	.65	-.6552
.20	-.3783	.70	-.1670
.25	-.3707	.75	-.0822
.30	-.4011	.80	-.0228
.35	-.4688	.85	.0374
.40	-.5090	.90	.1239
.45	-.5327	.95	.2238

TABLE 37. - PATH 3.

TOTAL TEMPERATURE = 93.8 K
TOTAL PRESSURE = 3.37 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 34.0 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.2066	.50	-.5947
.05	-.0780	.55	-.6219
.10	-.2595	.60	******
.15	-.3707	.65	-.5868
.20	-.3828	.70	-.1647
.25	-.3706	.75	-.0809
.30	-.4057	.80	-.0339
.35	-.4707	.85	.0322
.40	-.5089	.90	.1183
.45	-.5425	.95	.2231

TABLE 38. - PATH 3.

TOTAL TEMPERATURE = 93.1 K
TOTAL PRESSURE = 3.29 ATM
MACH INFINITY = .862
CHORD REYNOLDS NUMBER = 33.8 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.1988	.50	-.5818
.05	-.0726	.55	-.6140
.10	-.2534	.60	******
.15	-.3652	.65	-.6486
.20	-.3748	.70	-.1847
.25	-.3665	.75	-.0883
.30	-.4005	.80	-.0223
.35	-.4675	.85	.0401
.40	-.5036	.90	.1230
.45	-.5321	.95	.2233

TABLE 39. - PATH 3.

TOTAL TEMPERATURE = 92.8 K
TOTAL PRESSURE = 3.31 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 33.9 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.1981	.50	******
.05	-.0750	.55	-.6239
.10	-.2589	.60	-.6667
.15	-.3613	.65	-.5974
.20	-.3724	.70	-.1592
.25	-.3664	.75	-.0914
.30	-.4090	.80	-.0388
.35	-.4598	.85	.0180
.40	-.5064	.90	.1096
.45	******	.95	.2210

TABLE 40. - PATH 3.

TOTAL TEMPERATURE = 92.3 K
TOTAL PRESSURE = 3.22 ATM
MACH INFINITY = .854
CHORD REYNOLDS NUMBER = 33.3 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.1962	.50	******
.05	-.0758	.55	-.6232
.10	-.2594	.60	-.6594
.15	-.3564	.65	-.5079
.20	-.3707	.70	-.1567
.25	-.3652	.75	-.0945
.30	-.4086	.80	-.0398
.35	-.4607	.85	.0178
.40	-.5047	.90	.1107
.45	******	.95	.2197

TABLE 41. - PATH 3.

TOTAL TEMPERATURE = 92.1 K
TOTAL PRESSURE = 3.22 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 33.5 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.2031	.50	******
.05	-.0751	.55	-.6232
.10	-.2598	.60	-.6661
.15	-.3640	.65	-.6091
.20	-.3723	.70	-.1626
.25	-.3699	.75	-.0865
.30	-.4081	.80	-.0318
.35	-.4635	.85	.0177
.40	-.5078	.90	.1099
.45	******	.95	.2198

TABLE 42. - PATH 3.

TOTAL TEMPERATURE = 91.4 K
TOTAL PRESSURE = 3.21 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 33.7 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.1793	.50	******
.05	-.0761	.55	-.6167
.10	-.2563	.60	-.6545
.15	-.3508	.65	-.5813
.20	-.3664	.70	-.1557
.25	-.3627	.75	-.0866
.30	-.4051	.80	-.0348
.35	-.4573	.85	.0177
.40	-.5033	.90	.1073
.45	******	.95	.2177

TABLE 43. - PATH 3.

TOTAL TEMPERATURE = 90.3 K
TOTAL PRESSURE = 3.13 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 33.4 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.1843	.50	******
.05	-.0772	.55	-.6215
.10	-.2596	.60	-.6622
.15	-.3567	.65	-.5922
.20	-.3705	.70	-.1572
.25	-.3652	.75	-.0877
.30	-.4085	.80	-.0343
.35	-.4618	.85	.0188
.40	-.5084	.90	.1106
.45	******	.95	.2195

TABLE 44. - PATH 4.

TOTAL TEMPERATURE = 112.6 K
TOTAL PRESSURE = 5.00 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 38.5 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2003	.50	-.6003
.05	-.0850	.55	-.6244
.10	-.2640	.60	-.6767
.15	-.3775	.65	-.5926
.20	-.3893	.70	-.1649
.25	-.3757	.75	-.1020
.30	-.4109	.80	-.0321
.35	-.4788	.85	.0314
.40	-.5154	.90	.1201
.45	-.5449	.95	.2245

TABLE 45. - PATH 4.

TOTAL TEMPERATURE = 105.5 K
TOTAL PRESSURE = 4.50 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 38.2 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.2019	.50	-.5977
.05	-.0828	.55	-.6251
.10	-.2627	.60	-.6758
.15	-.3749	.65	-.6403
.20	-.3892	.70	-.1659
.25	-.3763	.75	-.0879
.30	-.4118	.80	-.0316
.35	-.4767	.85	.0323
.40	-.5127	.90	.1186
.45	-.5424	.95	.2229

TABLE 46. - PATH 4.

TOTAL TEMPERATURE = 103.4 K
TOTAL PRESSURE = 4.40 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 38.5 MILLION

DISTRIBUTION TAKEN ON DAY 2 OF TESTING

X/C	CP	X/C	CP
.00	1.1972	.50	-.5969
.05	-.0832	.55	-.6232
.10	-.2665	.60	-.6682
.15	-.3693	.65	-.5932
.20	-.3899	.70	-.1618
.25	-.3727	.75	-.0892
.30	-.4064	.80	-.0332
.35	-.4749	.85	.0299
.40	-.5141	.90	.1233
.45	-.5410	.95	.2246

TABLE 47. - PATH 4.

TOTAL TEMPERATURE = 101.5 K
TOTAL PRESSURE = 4.20 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 37.8 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.2035	.50	-.5977
.05	-.0776	.55	-.6248
.10	-.2578	.60	-.6773
.15	-.3737	.65	-.6098
.20	-.3851	.70	-.1698
.25	-.3725	.75	-.0873
.30	-.4076	.80	-.0287
.35	-.4754	.85	.0365
.40	-.5125	.90	.1216
.45	-.5457	.95	.2246

TABLE 48. - PATH 4.

TOTAL TEMPERATURE = 99.6 K
TOTAL PRESSURE = 4.10 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 38.0 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.2117	.50	-.5962
.05	-.0769	.55	-.6264
.10	-.2571	.60	-.6777
.15	-.3739	.65	-.6314
.20	-.3846	.70	-.1786
.25	-.3744	.75	-.0862
.30	-.4080	.80	-.0305
.35	-.4771	.85	.0360
.40	-.5132	.90	.1233
.45	-.5409	.95	.2244

TABLE 49. - PATH 4.

TOTAL TEMPERATURE = 97.1 K
TOTAL PRESSURE = 3.92 ATM
MACH INFINITY = .854
CHORD REYNOLDS NUMBER = 37.6 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.2190	.50	-.5990
.05	-.0746	.55	-.6224
.10	-.2540	.60	-.6730
.15	-.3731	.65	-.6583
.20	-.3761	.70	-.1644
.25	-.3713	.75	-.0872
.30	-.4120	.80	-.0304
.35	-.4753	.85	.0328
.40	-.5110	.90	.1211
.45	-.5404	.95	.2238

TABLE 50. - PATH 4.

TOTAL TEMPERATURE = 95.4 K
TOTAL PRESSURE = 3.82 ATM
MACH INFINITY = .854
CHORD REYNOLDS NUMBER = 37.6 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.2053	.50	-.5937
.05	-.0791	.55	-.6179
.10	-.2561	.60	-.6625
.15	-.3630	.65	-.5863
.20	-.3793	.70	-.1577
.25	-.3663	.75	-.0935
.30	-.4022	.80	-.0354
.35	-.4646	.85	.0263
.40	-.5085	.90	.1157
.45	-.5426	.95	.2226

TABLE 51. - PATH 4.

TOTAL TEMPERATURE = 93.9 K
TOTAL PRESSURE = 3.72 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 37.5 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.1963	.50	-.5918
.05	-.0743	.55	-.6180
.10	-.2558	.60	-.6676
.15	-.3573	.65	-.6418
.20	-.3730	.70	-.1663
.25	-.3647	.75	-.0882
.30	-.4009	.80	-.0331
.35	-.4660	.85	.0320
.40	-.5055	.90	.1212
.45	-.5338	.95	.2229

TABLE 52. - PATH 4.

TOTAL TEMPERATURE = 92.5 K
TOTAL PRESSURE = 3.62 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 37.4 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.1974	.50	-.5906
.05	-.0743	.55	-.6143
.10	-.2507	.60	-.6622
.15	-.3540	.65	-.6432
.20	-.3697	.70	-.1679
.25	-.3636	.75	-.0943
.30	-.4013	.80	-.0318
.35	-.4644	.85	.0288
.40	-.5050	.90	.1201
.45	-.5372	.95	.2208

TABLE 53. - PATH 4.

TOTAL TEMPERATURE = 90.8 K
TOTAL PRESSURE = 3.50 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 37.1 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.1849	.50	-.5870
.05	-.0743	.55	-.6090
.10	-.2542	.60	-.6602
.15	-.3408	.65	-.4266
.20	-.3655	.70	-.1575
.25	-.3556	.75	-.1023
.30	-.4023	.80	-.0450
.35	-.4625	.85	.0231
.40	-.5049	.90	.1115
.45	-.5369	.95	.2142

TABLE 54. - PATH 5.

TOTAL TEMPERATURE = 106.4 K
TOTAL PRESSURE = 4.97 ATM
MACH INFINITY = .861
CHORD REYNOLDS NUMBER = 41.8 MILLION

DISTRIBUTION TAKEN ON DAY 3 OF TESTING

X/C	CP	X/C	CP
.00	1.1927	.50	-.5904
.05	-.0773	.55	-.6168
.10	-.2578	.60	-.6725
.15	-.3723	.65	-.6308
.20	-.3786	.70	-.1716
.25	-.3715	.75	-.0837
.30	-.4056	.80	-.0275
.35	-.4719	.85	.0390
.40	-.5075	.90	.1232
.45	-.5381	.95	.2226

TABLE 55. - PATH 5.

TOTAL TEMPERATURE = 104.4 K
TOTAL PRESSURE = 4.84 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 41.7 MILLION

DISTRIBUTION TAKEN ON DAY 3 OF TESTING

X/C	CP	X/C	CP
.00	1.2015	.50	-.5944
.05	-.0789	.55	-.6237
.10	-.2601	.60	-.6692
.15	-.3728	.65	-.5906
.20	-.3828	.70	-.1637
.25	-.3726	.75	-.0865
.30	-.4070	.80	-.0281
.35	-.4696	.85	.0293
.40	-.5093	.90	.1218
.45	-.5378	.95	.2246

TABLE 56. - PATH 5.

TOTAL TEMPERATURE = 102.3 K
TOTAL PRESSURE = 4.72 ATM
MACH INFINITY = .859
CHORD REYNOLDS NUMBER = 42.0 MILLION

DISTRIBUTION TAKEN ON DAY 3 OF TESTING

X/C	CP	X/C	CP
.00	1.1957	.50	-.5956
.05	-.0803	.55	-.6244
.10	-.2621	.60	-.6780
.15	-.3693	.65	-.6530
.20	-.3835	.70	-.1739
.25	-.3721	.75	-.0864
.30	-.4081	.80	-.0284
.35	-.4746	.85	.0340
.40	-.5121	.90	.1261
.45	-.5395	.95	.2255

TABLE 57. - PATH 5.

TOTAL TEMPERATURE = 100.6 K
TOTAL PRESSURE = 4.57 ATM
MACH INFINITY = .855
CHORD REYNOLDS NUMBER = 41.7 MILLION

DISTRIBUTION TAKEN ON DAY 8 OF TESTING

X/C	CP	X/C	CP
.00	1.2027	.50	-.5959
.05	-.0788	.55	-.6213
.10	-.2608	.60	-.6776
.15	-.3718	.65	-.6482
.20	-.3684	.70	-.1671
.25	-.3770	.75	-.0821
.30	-.4105	.80	-.0289
.35	-.4651	.85	.0352
.40	-.5119	.90	.1181
.45	******	.95	.2221

TABLE 58. - PATH 5.

TOTAL TEMPERATURE = 98.6 K
TOTAL PRESSURE = 4.42 ATM
MACH INFINITY = .854
CHORD REYNOLDS NUMBER = 41.5 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.1967	.50	-.5946
.05	-.0835	.55	-.6268
.10	-.2632	.60	******
.15	-.3746	.65	-.6240
.20	-.3871	.70	-.1703
.25	-.3775	.75	-.0676
.30	-.4089	.80	-.0314
.35	-.4769	.85	.0329
.40	-.5139	.90	.1243
.45	-.5426	.95	.2277

TABLE 59. - PAT: 5.

TOTAL TEMPERATURE = 96.7 K
TOTAL PRESSURE = 4.28 ATM
MACH INFINITY = .859
CHORD REYNOLDS NUMBER = 41.5 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.2022	.50	-.5891
.05	-.0760	.55	-.6202
.10	-.2537	.60	******
.15	-.3720	.65	-.6963
.20	-.3810	.70	-.1766
.25	-.3730	.75	-.0696
.30	-.4119	.80	-.0246
.35	-.4731	.85	.0379
.40	-.5141	.90	.1232
.45	-.5409	.95	.2251

TABLE 60. - PATH 5.

TOTAL TEMPERATURE = 96.3 K
TOTAL PRESSURE = 4.28 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 41.7 MILLION

DISTRIBUTION TAKEN ON DAY 5 OF TESTING

X/C	CP	X/C	CP
.00	1.1945	.50	******
.05	-.0783	.55	-.6235
.10	-.2646	.60	-.6686
.15	-.3666	.65	-.6209
.20	-.3716	.70	-.1683
.25	-.3692	.75	-.0859
.30	-.4061	.80	-.0284
.35	-.4643	.85	.0211
.40	-.5084	.90	.1095
.45	******	.95	.2240

TABLE 61. - PATH 5.

TOTAL TEMPERATURE = 95.7 K
TOTAL PRESSURE = 4.21 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 41.4 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.1900	.50	******
.05	-.0723	.55	-.6235
.10	-.2556	.60	-.6713
.15	-.3627	.65	-.6673
.20	-.3721	.70	-.1665
.25	-.3708	.75	-.0859
.30	-.4081	.80	-.0319
.35	-.4629	.85	.0215
.40	-.5098	.90	.1121
.45	******	.95	.2208

TABLE 62. - PATH 5.

TOTAL TEMPERATURE = 95.6 K
TOTAL PRESSURE = 4.20 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 41.4 MILLION

DISTRIBUTION TAKEN ON DAY 8 OF TESTING

X/C	CP	X/C	CP
.00	1.1883	.50	-.5935
.05	-.0761	.55	-.6183
.10	-.2598	.60	-.6682
.15	-.3539	.65	-.6498
.20	-.3639	.70	-.1604
.25	-.3680	.75	-.0929
.30	-.4075	.80	-.0335
.35	-.4599	.85	.0306
.40	-.5064	.90	.1156
.45	******	.95	.2196

TABLE 63. - PATH 5.

TOTAL TEMPERATURE = 95.3 K
TOTAL PRESSURE = 4.15 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 41.1 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.1936	.50	-.5951
.05	-.0765	.55	-.6203
.10	-.2551	.60	******
.15	-.3689	.65	-.6205
.20	-.3821	.70	-.1673
.25	-.3724	.75	-.0730
.30	-.4066	.80	-.0274
.35	-.4729	.85	.0352
.40	-.5129	.90	.1217
.45	-.5372	.95	.2240

TABLE 64. - PATH 5.

TOTAL TEMPERATURE = 93.9 K
TOTAL PRESSURE = 4.09 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 41.3 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.1971	.50	******
.05	-.0711	.55	-.6238
.10	-.2569	.60	-.6677
.15	-.3604	.65	-.6419
.20	-.3706	.70	-.1696
.25	-.3708	.75	-.0654
.30	-.4068	.80	-.0357
.35	-.4616	.85	.0201
.40	-.5067	.90	.1105
.45	******	.95	.2205

TABLE 65. – PATH 5.

TOTAL TEMPERATURE = 93.7 K
TOTAL PRESSURE = 4.09 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 41.4 MILLION

DISTRIBUTION TAKEN ON DAY 8 OF TESTING

X/C	CP	X/C	CP
.00	1.1803	.50	-.5861
.05	-.0763	.55	-.6108
.10	-.2554	.60	-.6613
.15	-.3410	.65	-.5624
.20	-.3554	.70	-.1524
.25	-.3558	.75	-.0997
.30	-.4039	.80	-.0430
.35	-.4540	.85	.0230
.40	-.5049	.90	.1103
.45	******	.95	.2141

TABLE 66. – PATH 5.

TOTAL TEMPERATURE = 93.1 K
TOTAL PRESSURE = 4.00 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 41.0 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.2056	.50	******
.05	-.0725	.55	-.6268
.10	-.2558	.60	-.6657
.15	-.3634	.65	-.6121
.20	-.3700	.70	-.1592
.25	-.3673	.75	-.0868
.30	-.4074	.80	-.0320
.35	-.4631	.85	.0215
.40	-.5083	.90	.1124
.45	******	.95	.2222

TABLE 67. - PATH 6.

B L A N K

TABLE 68. - PATH 6.

TOTAL TEMPERATURE = 101.2 K
TOTAL PRESSURE = 4.84 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 43.8 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.1931	.50	******
.05	-.0799	.55	-.6258
.10	-.2616	.60	-.6692
.15	-.3728	.65	-.6482
.20	-.3742	.70	-.1842
.25	-.3747	.75	-.0836
.30	-.4105	.80	-.0332
.35	-.4652	.85	.0245
.40	-.5095	.90	.1122
.45	******	.95	.2247

TABLE 69. - PATH 6.

TOTAL TEMPERATURE = 100.2 K
TOTAL PRESSURE = 4.79 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 44.0 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.1995	.50	******
.05	-.0753	.55	-.6238
.10	-.2564	.60	-.6681
.15	-.3691	.65	-.6914
.20	-.3680	.70	-.1771
.25	-.3717	.75	-.0819
.30	-.4112	.80	-.0246
.35	-.4623	.85	.0219
.40	-.5125	.90	.1108
.45	******	.95	.2218

TABLE 70. - PATH 6.

TOTAL TEMPERATURE = 99.0 K
TOTAL PRESSURE = 4.72 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 44.1 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.1992	.50	-.5907
.05	-.0771	.55	-.6179
.10	-.2562	.60	-.6712
.15	-.3743	.65	-.6772
.20	-.3789	.70	-.1698
.25	-.3713	.75	-.0642
.30	-.4066	.80	-.0242
.35	-.4712	.85	.0390
.40	-.5113	.90	.1266
.45	-.5350	.95	.2272

TABLE 71. – PATH 6.

TOTAL TEMPERATURE = 98.2 K
TOTAL PRESSURE = 4.64 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 43.9 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.1992	.50	******
.05	-.0726	.55	-.6223
.10	-.2566	.60	-.6692
.15	-.3684	.65	-.6918
.20	-.3695	.70	-.1890
.25	-.3722	.75	-.0793
.30	-.4092	.80	-.0217
.35	-.4616	.85	.0266
.40	-.5087	.90	.1163
.45	******	.95	.2253

TABLE 72. – PATH 6.

TOTAL TEMPERATURE = 97.2 K
TOTAL PRESSURE = 4.56 ATM
MACH INFINITY = .856
CHORD REYNOLDS NUMBER = 43.8 MILLION

DISTRIBUTION TAKEN ON DAY 6 OF TESTING

X/C	CP	X/C	CP
.00	1.2009	.50	******
.05	-.0749	.55	-.6268
.10	-.2574	.60	-.6719
.15	-.3703	.65	-.6831
.20	-.3725	.70	-.1691
.25	-.3754	.75	-.0825
.30	-.4083	.80	-.0306
.35	-.4644	.85	.0234
.40	-.5096	.90	.1136
.45	******	.95	.2250

TABLE 73. - PATH 6.

TOTAL TEMPERATURE = 96.2 K
TOTAL PRESSURE = 4.48 ATM
MACH INFINITY = .858
CHORD REYNOLDS NUMBER = 43.7 MILLION

DISTRIBUTION TAKEN ON DAY 8 OF TESTING

X/C	CP	X/C	CP
.00	1.1861	.50	-.5876
.05	-.0761	.55	-.6112
.10	-.2571	.60	-.6639
.15	-.3559	.65	-.5739
.20	-.3605	.70	-.1538
.25	-.3648	.75	-.0904
.30	-.4057	.80	-.0365
.35	-.4560	.85	.0327
.40	-.5033	.90	.1164
.45	******	.95	.2184

TABLE 74. - PATH 6.

TOTAL TEMPERATURE = 95.6 K
TOTAL PRESSURE = 4.39 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 43.3 MILLION

DISTRIBUTION TAKEN ON DAY 4 OF TESTING

X/C	CP	X/C	CP
.00	1.1812	.50	-.5915
.05	-.0742	.55	-.6172
.10	-.2538	.60	-.6418
.15	-.3651	.65	-.6656
.20	-.3786	.70	-.1673
.25	-.3661	.75	-.0641
.30	-.3999	.80	-.0292
.35	-.4656	.85	.0358
.40	-.5075	.90	.1236
.45	-.5328	.95	.2249

TABLE 75. - PATH 6.

TOTAL TEMPERATURE = 93.5 K
TOTAL PRESSURE = 4.30 ATM
MACH INFINITY = .857
CHORD REYNOLDS NUMBER = 43.7 MILLION

DISTRIBUTION TAKEN ON DAY 8 OF TESTING

X/C	CP	X/C	CP
.00	1.1817	.50	-.5808
.05	-.0757	.55	-.6054
.10	-.2578	.60	-.6556
.15	-.3307	.65	-.4580
.20	-.3492	.70	-.1556
.25	-.3530	.75	-.1046
.30	-.4062	.80	-.0483
.35	-.4531	.85	.0161
.40	-.5037	.90	.1045
.45	******	.95	.2082

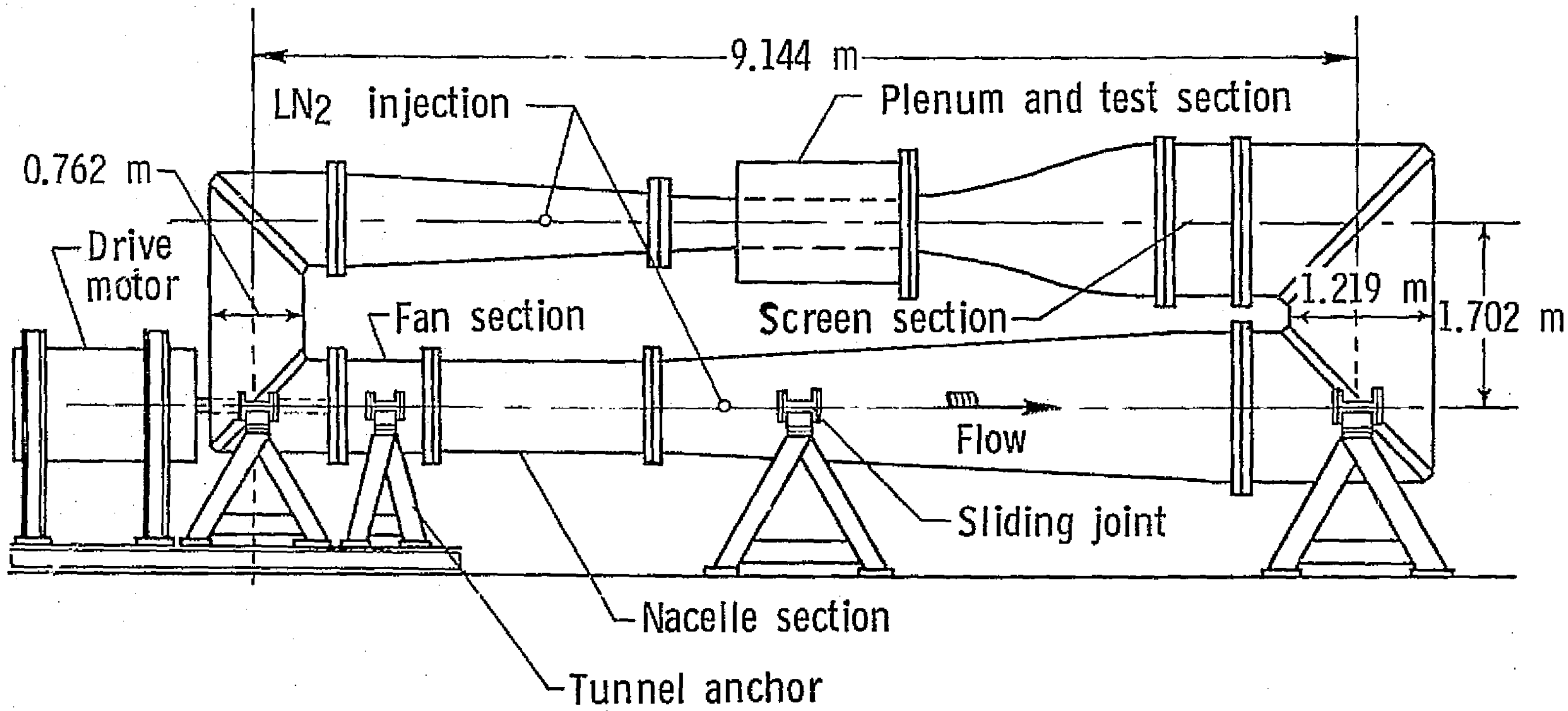
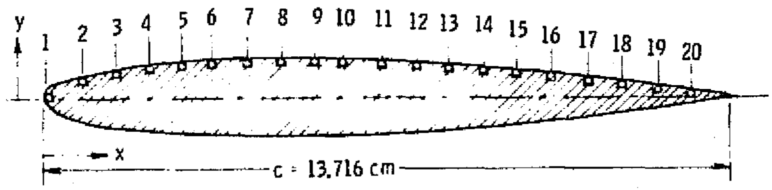
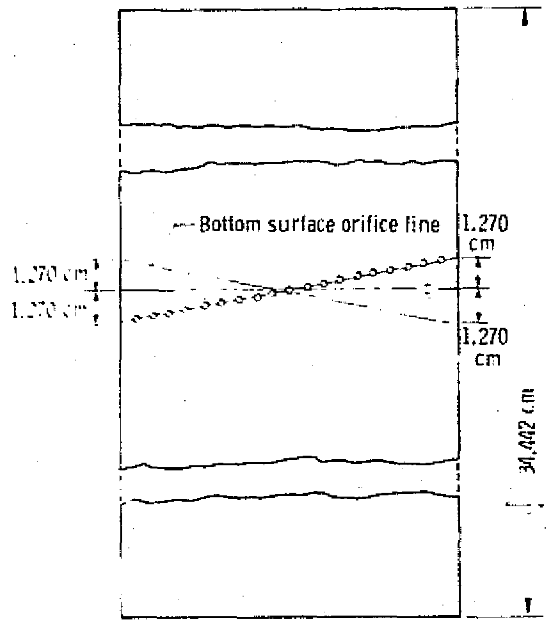


Figure 1. - Schematic of Langley 1/3-meter transonic cryogenic tunnel.





Airfoil coordinates	
x	y
0	0
0.175	± 0.249
.348	± 0.335
.699	± 0.447
1.046	± 0.523
1.372	± 0.582
2.062	± 0.668
2.743	± 0.726
4.115	± 0.800
5.486	± 0.823
6.858	± 0.800
8.230	± 0.729
9.601	± 0.615
10.973	± 0.455
12.344	± 0.257
13.030	± 0.140
13.716	± 0.015

Orifice locations		
Orifice number	Orifice station x, cm	$\frac{x}{c}$
1	0	0
2	0.698	0.0509
3	1.372	.1000
4	2.062	.1504
5	2.743	.2000
6	3.429	.2500
7	4.115	.3000
8	4.801	.3500
9	5.486	.4000
10	6.172	.4500
11	6.858	.5000
12	7.544	.5500
13	8.230	.6000
14	8.915	.6500
15	9.601	.7000
16	10.287	.7500
17	10.973	.8000
18	11.659	.8500
19	12.344	.9000
20	13.030	.9500

Figure 2. - Two dimensional NACA 0012-64 airfoil. Lower surface orifices are located at same x/c location as those on upper surface.

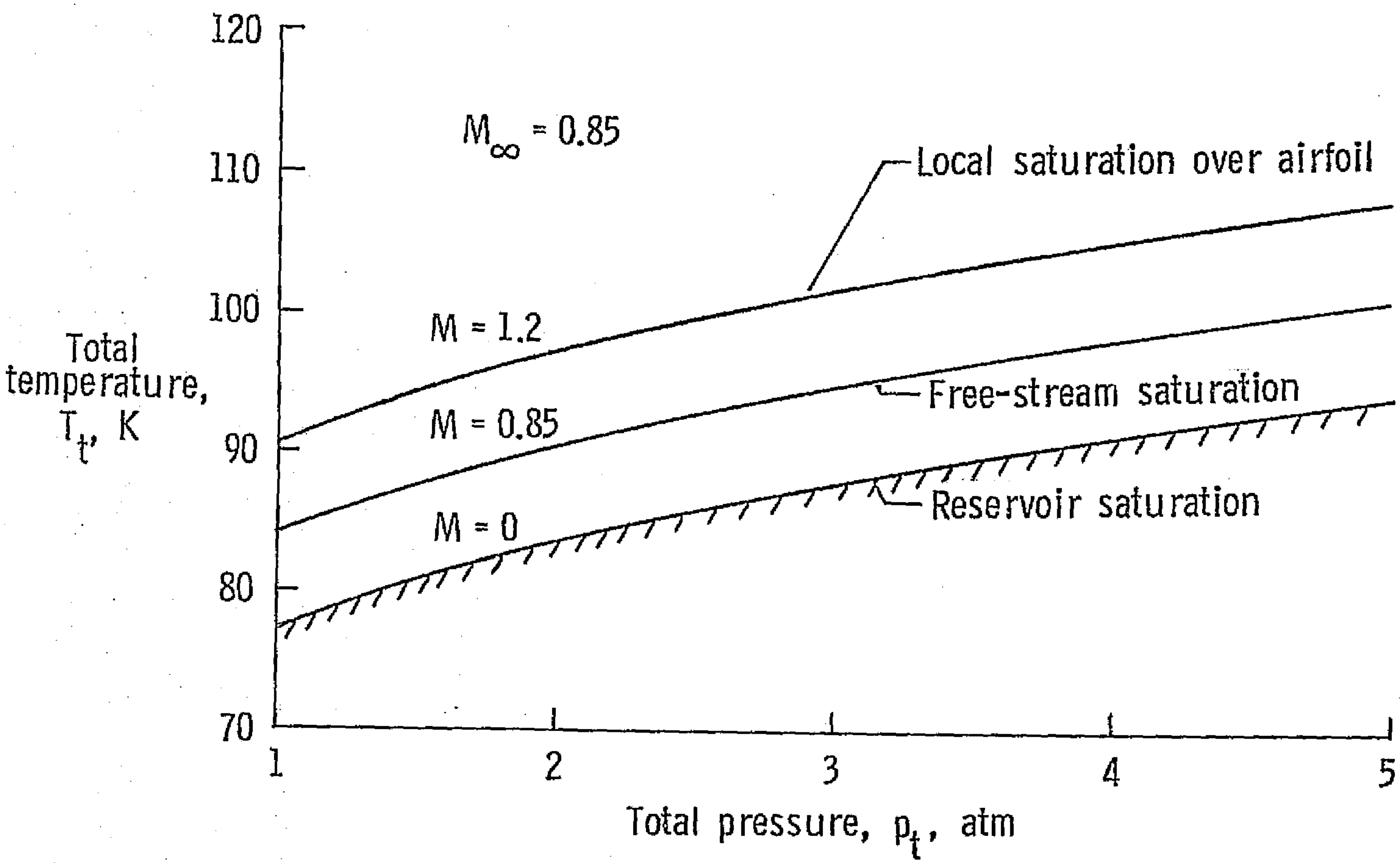


Figure 3. - The three stages of saturation as a function of total pressure.

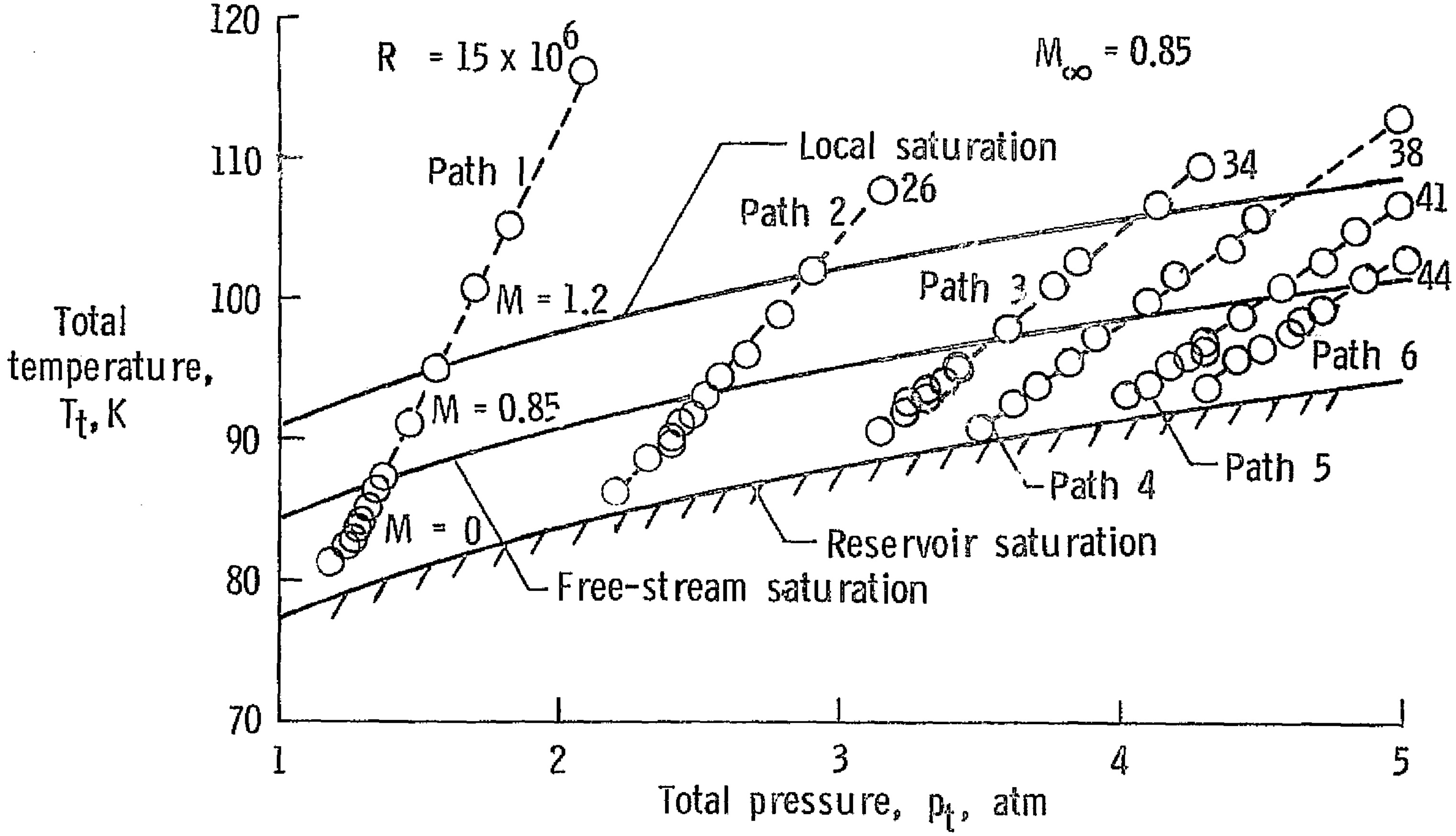
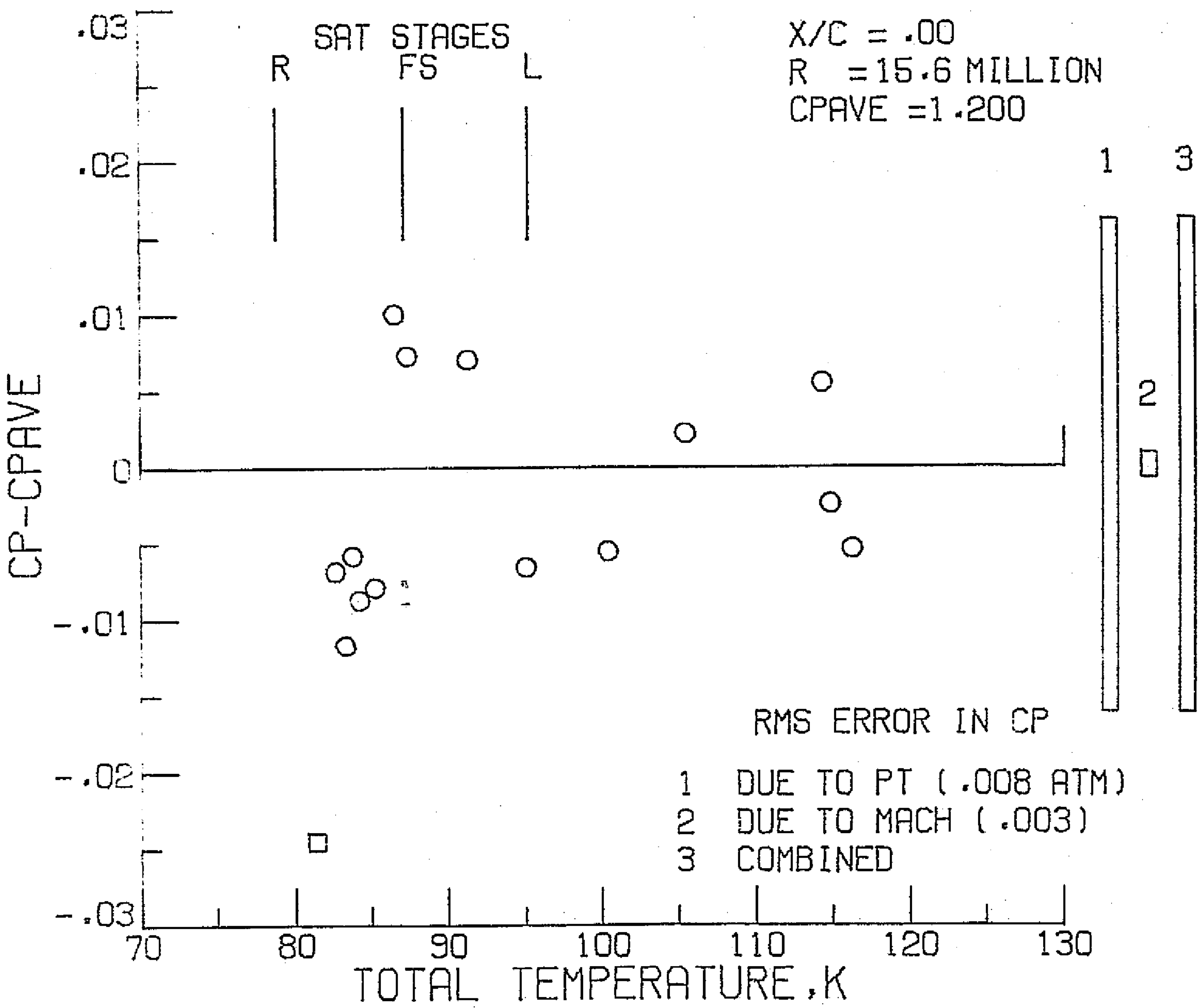


Figure 4. - Constant Reynolds number paths and total conditions sampled.



SAT STAGES
R
FS
L
X/C = .00
R =15.6 MILLION
CPAVE =1.200
1
2
3
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
RMS ERROR IN CP
1 DUE TO PT (.008 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 5.

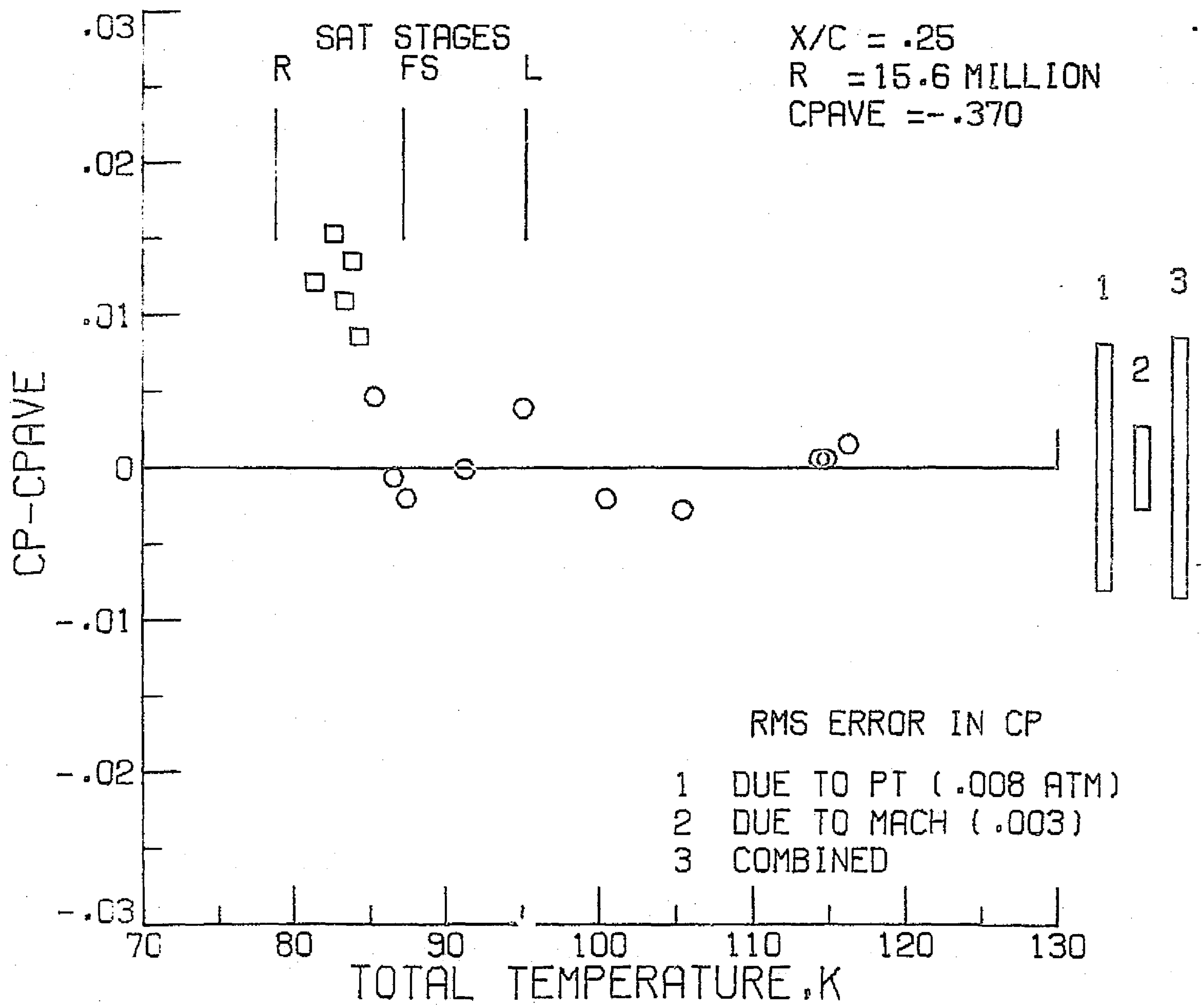

SAT STAGES
R
FS
L
X/C = .25
R =15.6 MILLION
CPAVE =-.370
CP-CPAVE
.03
.02
.01
0
-.01
-.02
-.03
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.008 ATM)
2 DUE TO MACH (.003)
3 COMBINED

Figure 6.

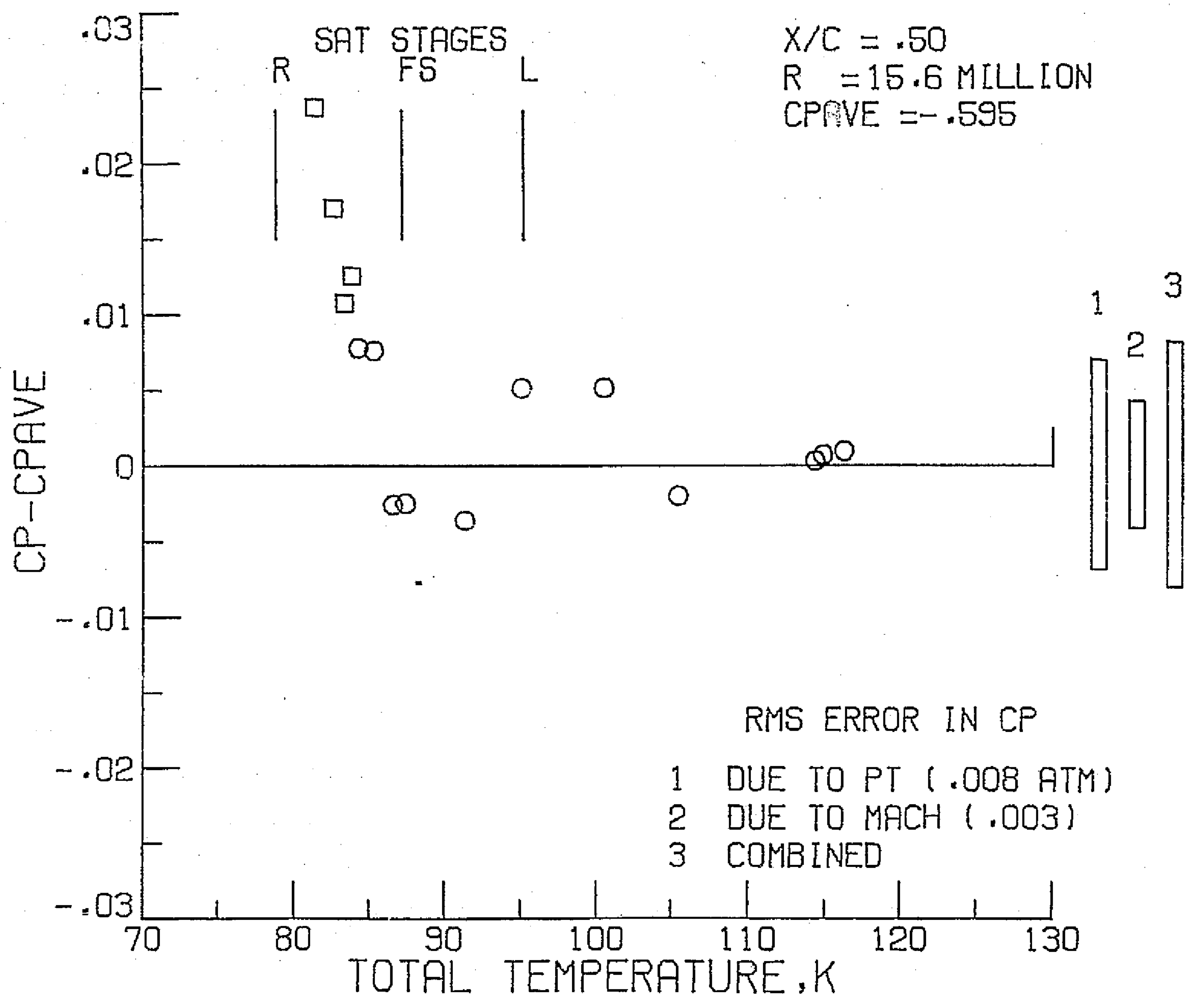

SAT STAGES
R
FS
L
X/C = .50
R =15.6 MILLION
CPAVE =-.595
1
2
3
CP-CPAVE
.03
.02
.01
0
-.01
-.02
-.03
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K
RMS ERROR IN CP
1 DUE TO PT (.008 ATM)
2 DUE TO MACH (.003)
3 COMBINED

Figure 7.

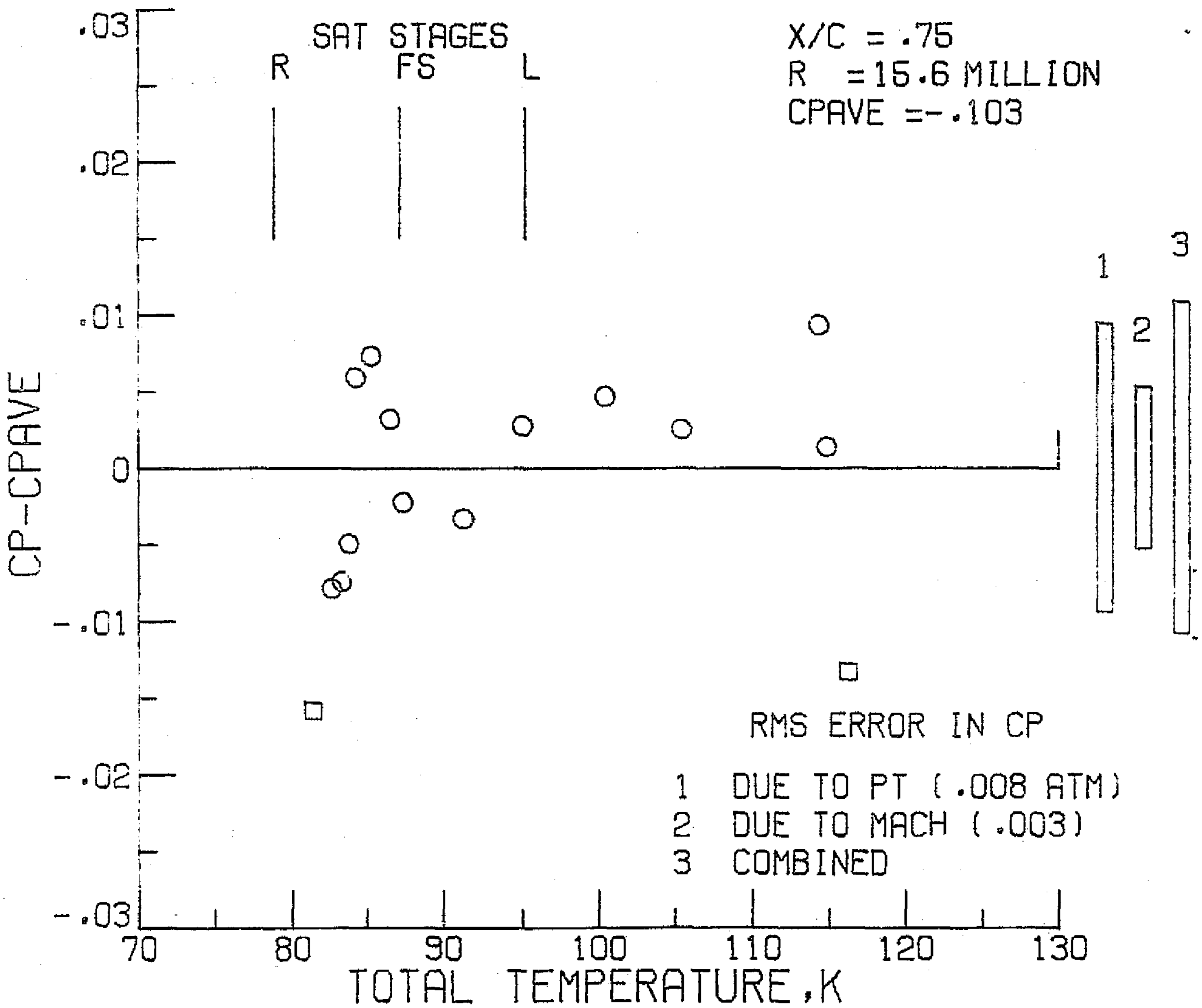

SAT STAGES
R
FS
L
X/C = .75
R =15.6 MILLION
CPAVE =-.103
CP-CPAVE
.03
.02
.01
0
-.01
-.02
-.03
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.008 ATM)
2 DUE TO MACH (.003)
3 COMBINED

Figure 8.

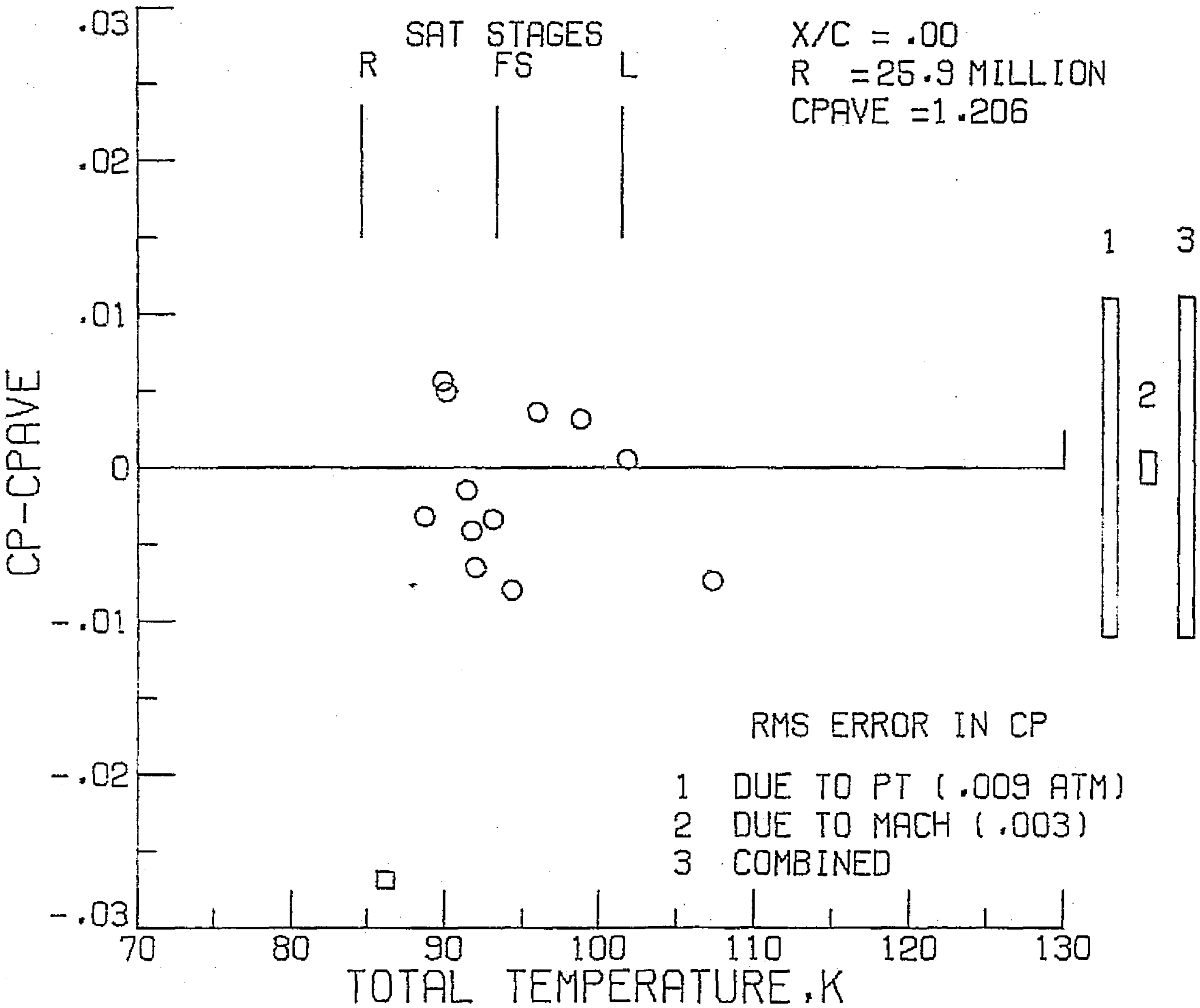

SAT STAGES
R
FS
L
X/C = .00
R =25.9 MILLION
CPAVE =1.206
1
2
3
CP-CPAVE
.03
.02
.01
0
-.01
-.02
-.03
RMS ERROR IN CP
1 DUE TO PT (.009 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 9.

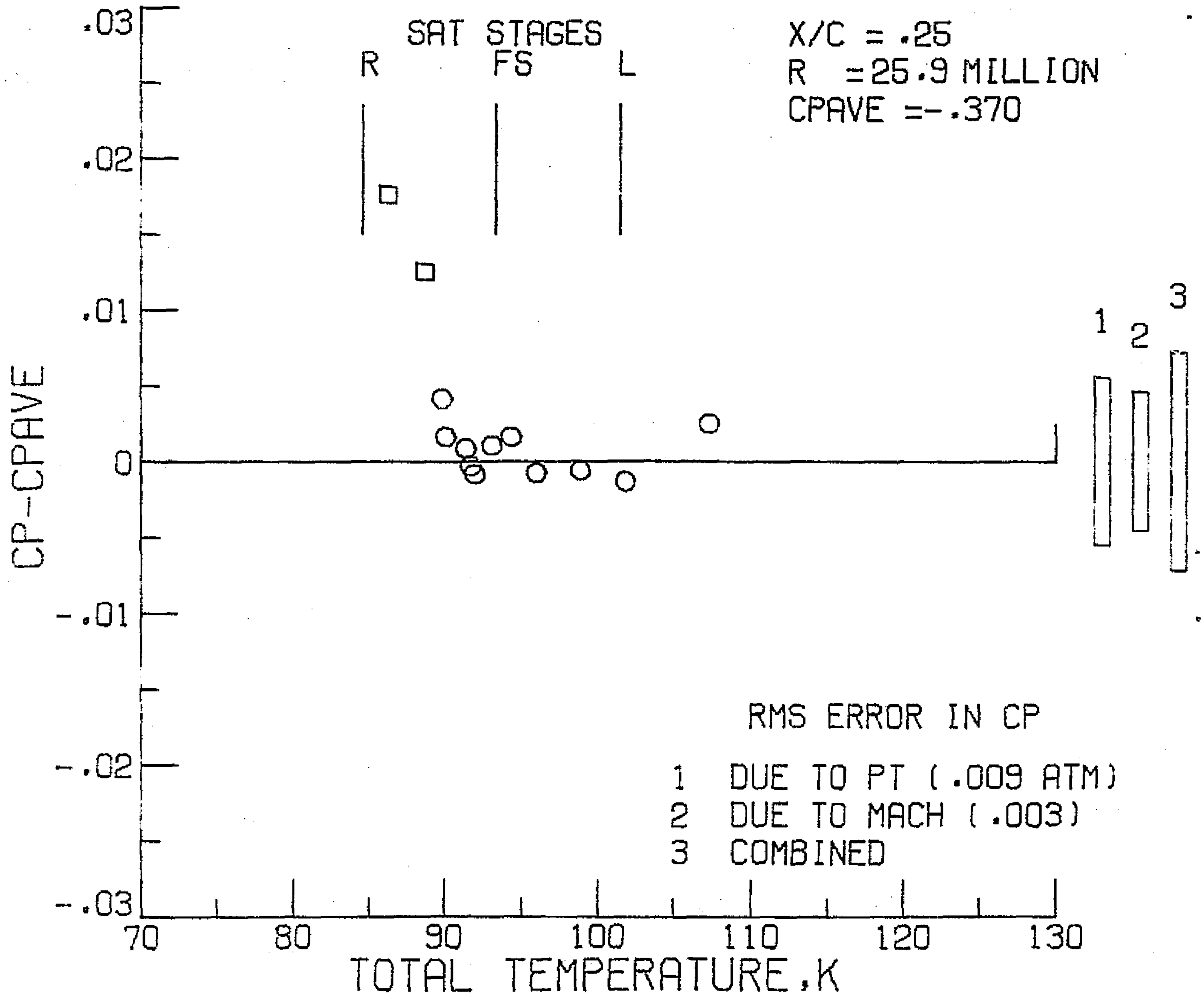

SAT STAGES
R
FS
L
X/C = .25
R =25.9 MILLION
CPAVE =-.370
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.009 ATM)
2 DUE TO MACH (.003)
3 COMBINED
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 10.

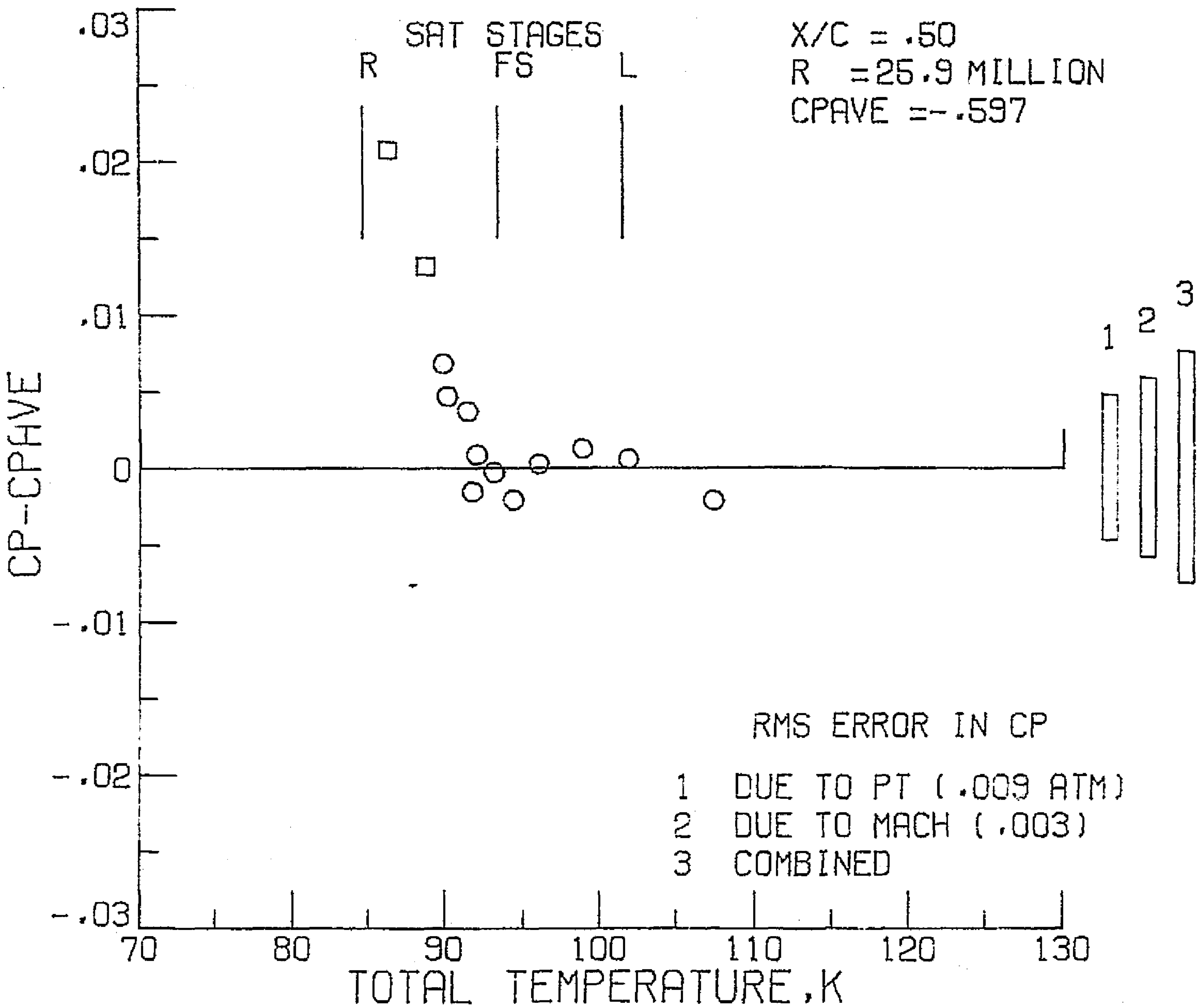
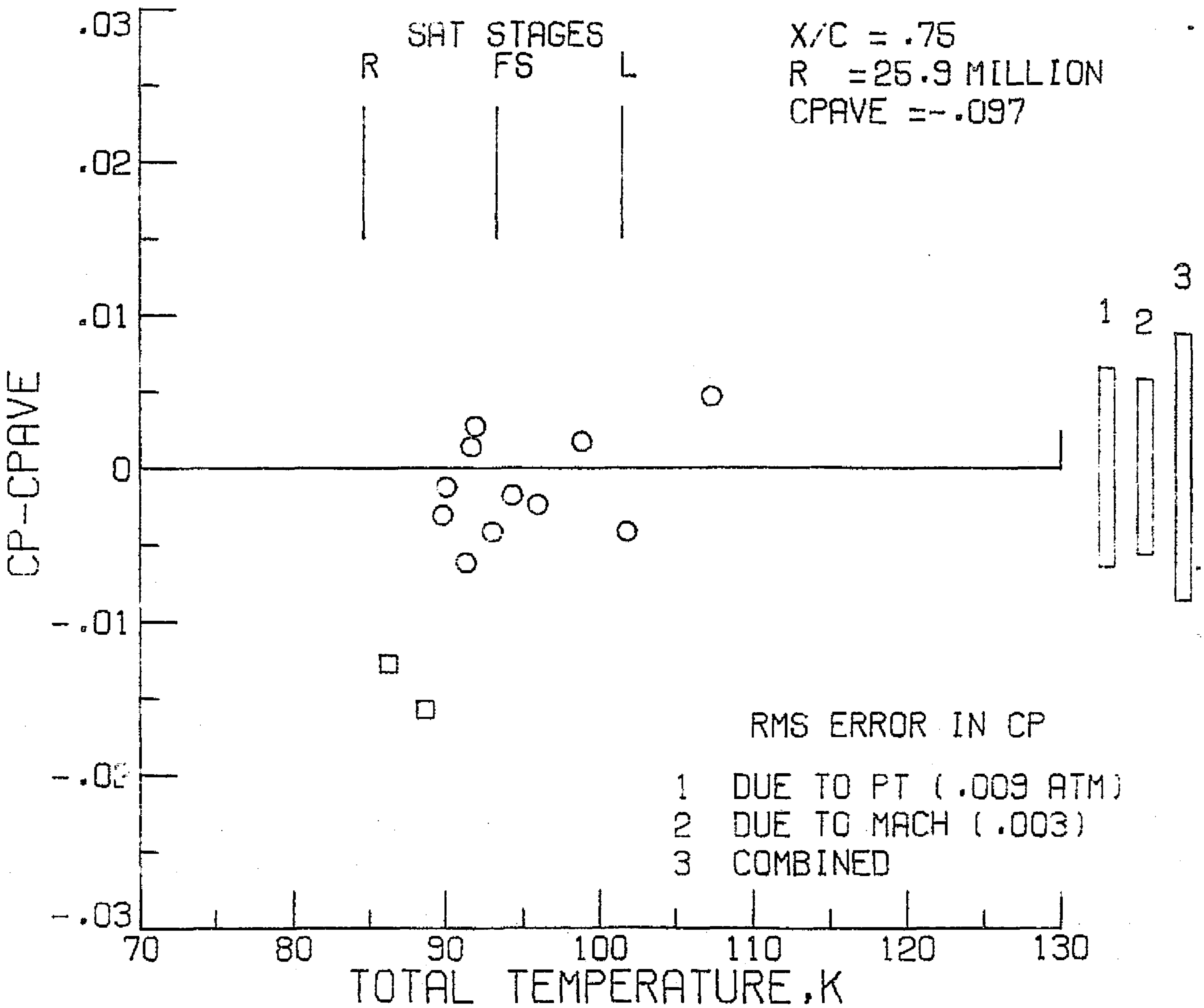

.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
SAT STAGES
R
FS
L
X/C = .50
R =25.9 MILLION
CPAVE =-.597
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.009 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE, K

Figure 11.



.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
SAT STAGES
R
FS
L
X/C = .75
R =25.9 MILLION
CPAVE =-.097
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.009 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 12.

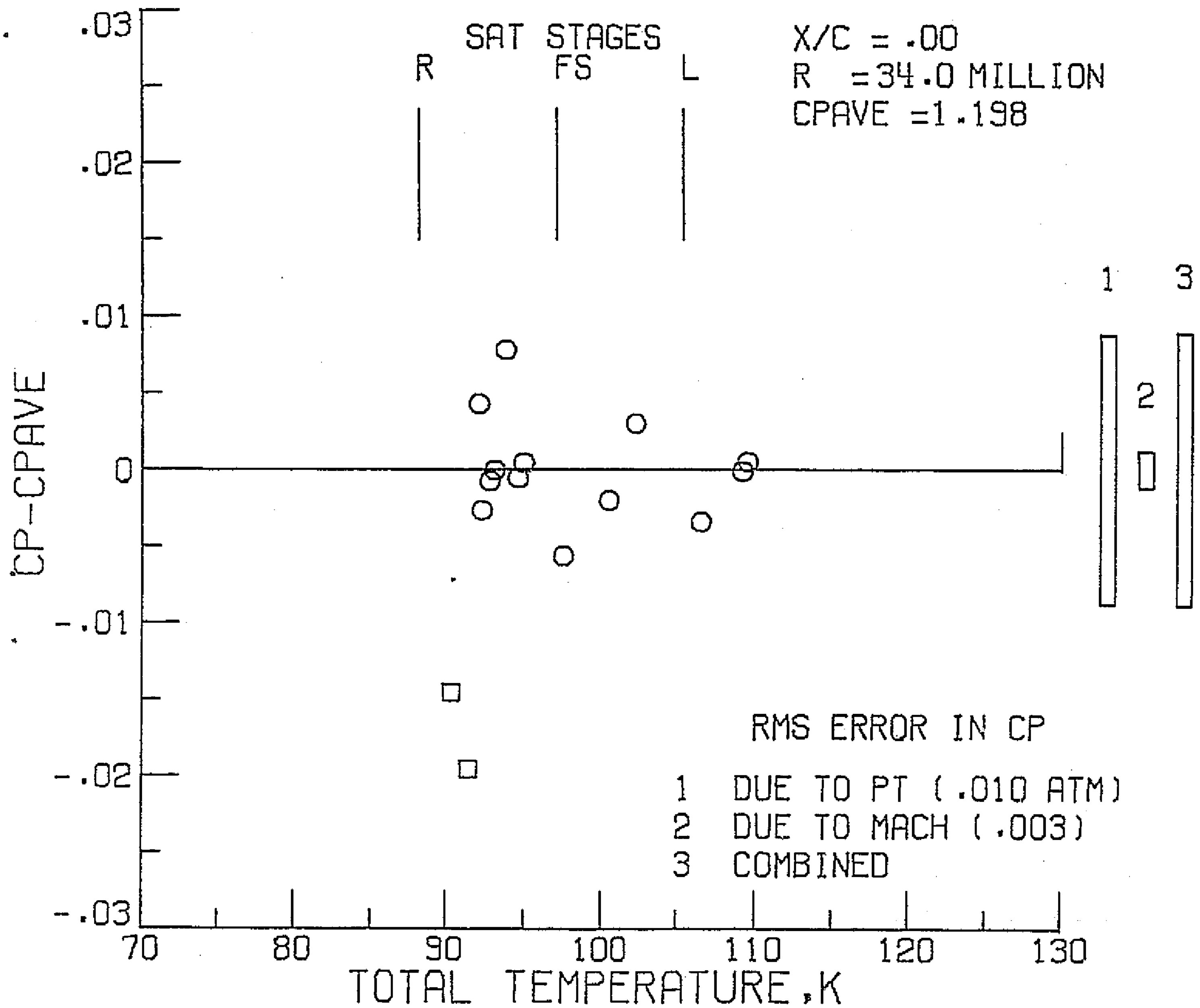

SAT STAGES
R
FS
L
X/C = .00
R = 34.0 MILLION
CPAVE = 1.198
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.010 ATM)
2 DUE TO MACH (.003)
3 COMBINED
CP-CPAVE
.03
.02
.01
0
-.01
-.02
-.03
70
80
90
100
110
120
130
TOTAL TEMPERATURE, K

Figure 13.

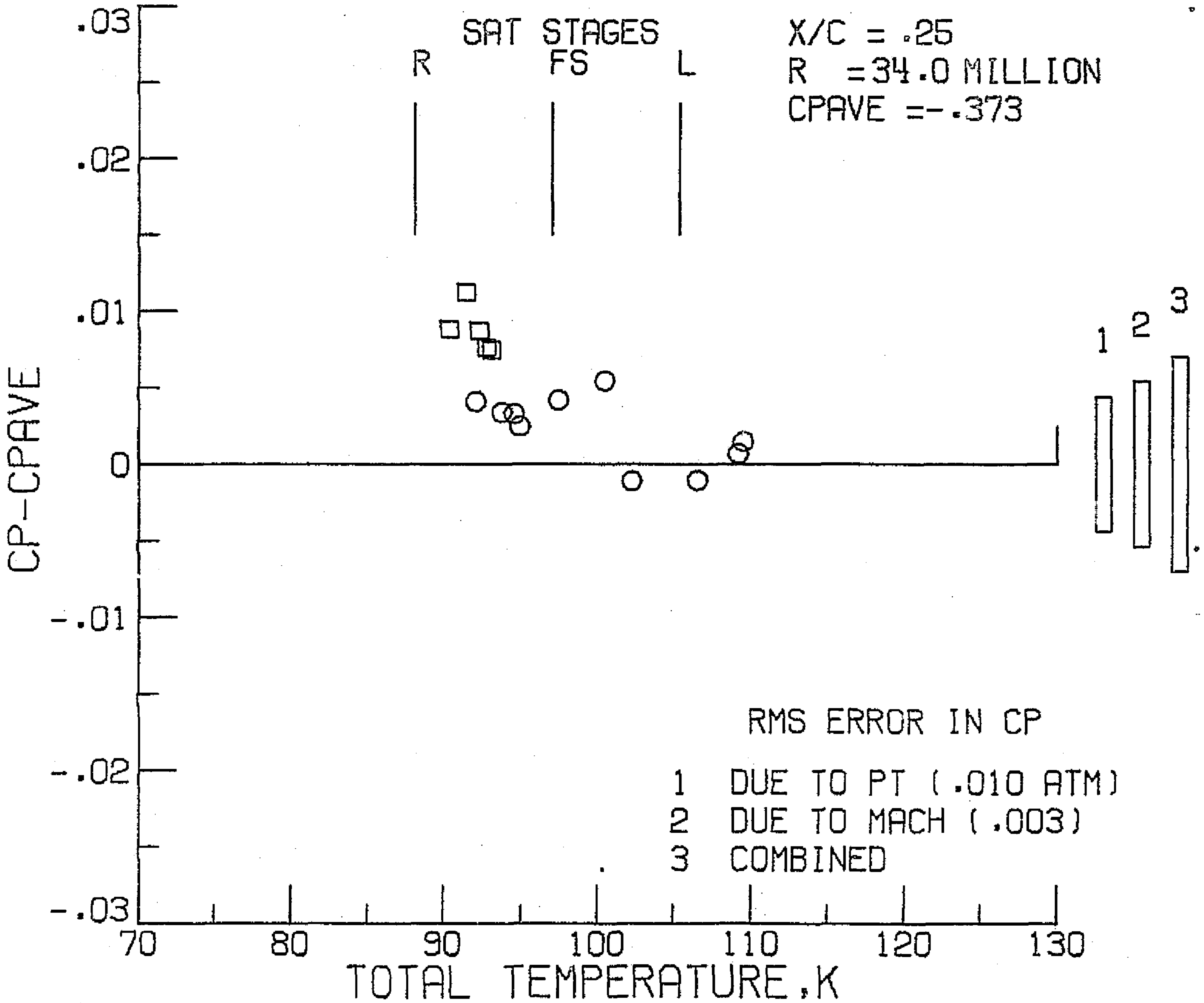

SAT STAGES
R
FS
L
X/C = .25
R =34.0 MILLION
CPAVE =-.373
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.010 ATM)
2 DUE TO MACH (.003)
3 COMBINED

Figure 14.

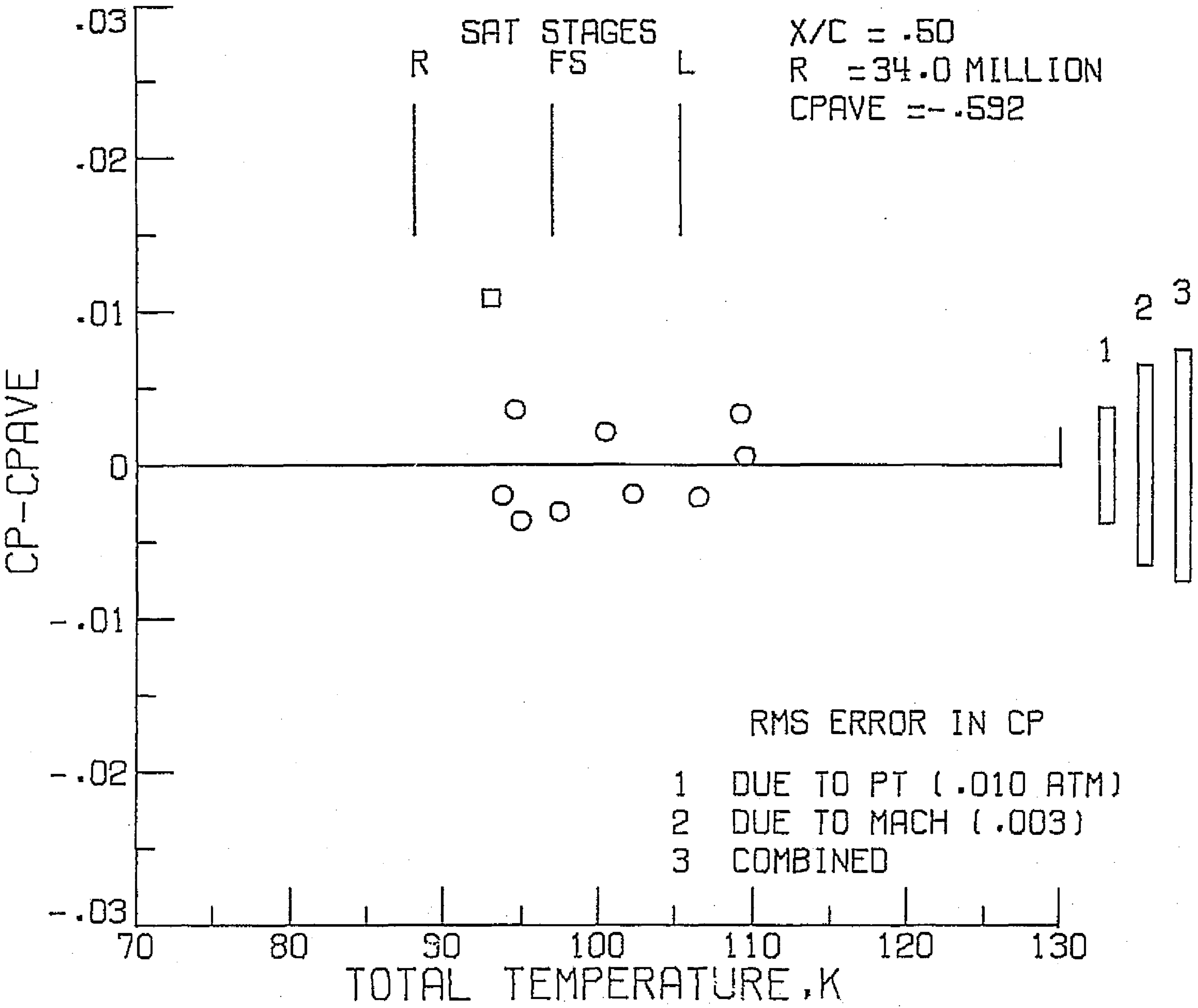

SAT STAGES
R
FS
L
X/C = .50
R =34.0 MILLION
CPAVE =-.592
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.010 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 15.

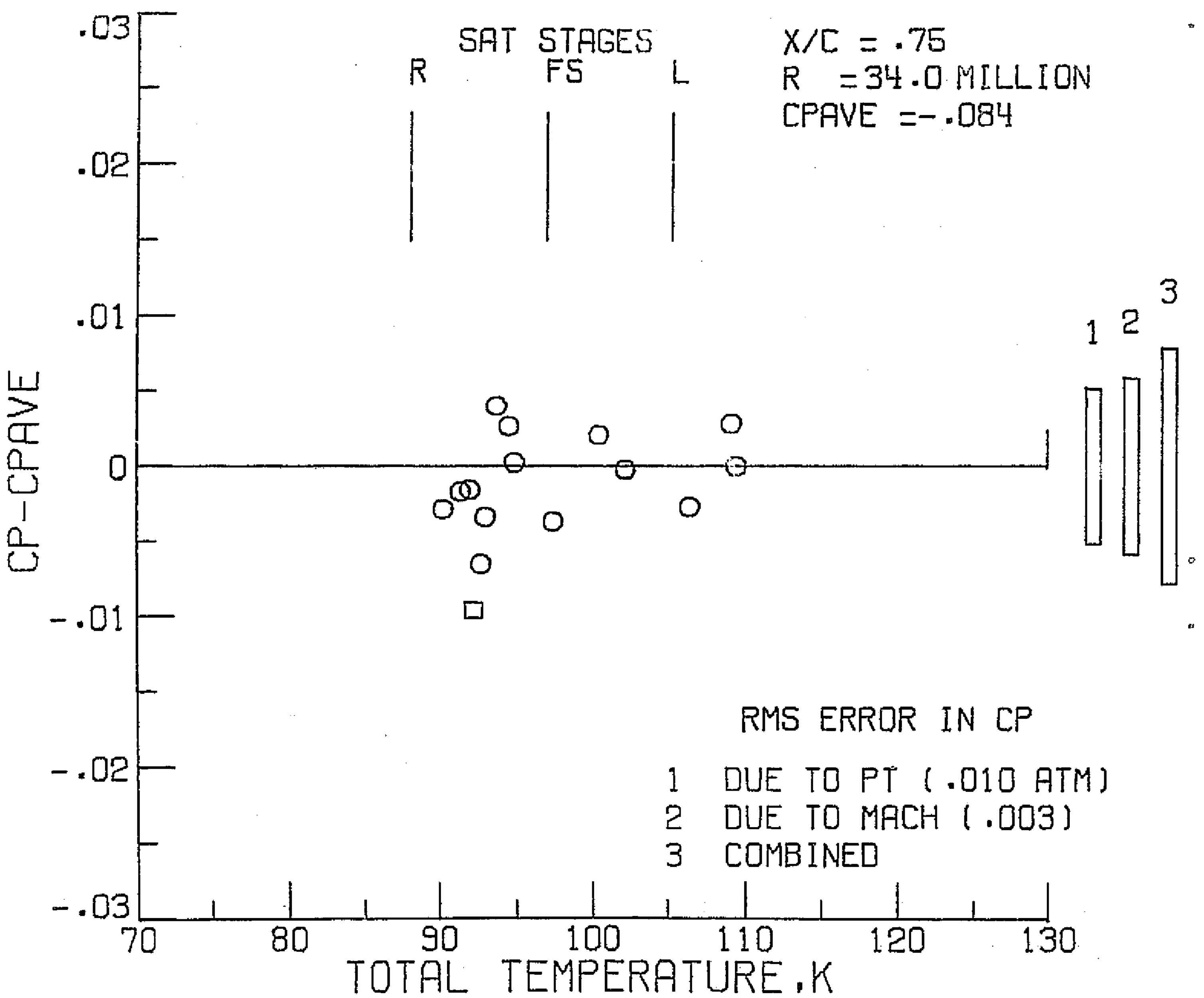

SAT STAGES
R
FS
L
X/C = .75
R =34.0 MILLION
CPAVE =-.084
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.010 ATM)
2 DUE TO MACH (.003)
3 COMBINED
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 16.

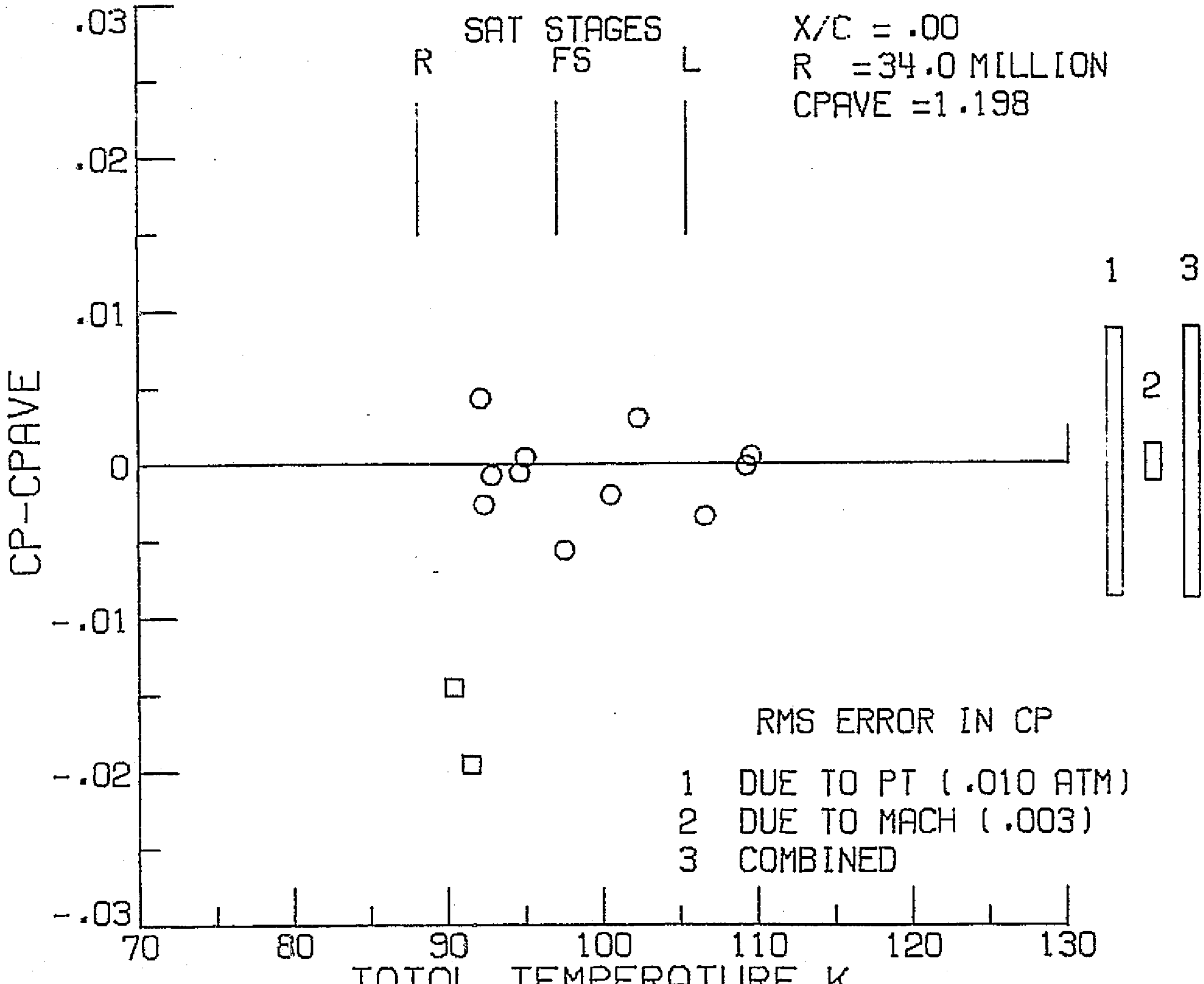


Figure 17. - Day 4 data not included.

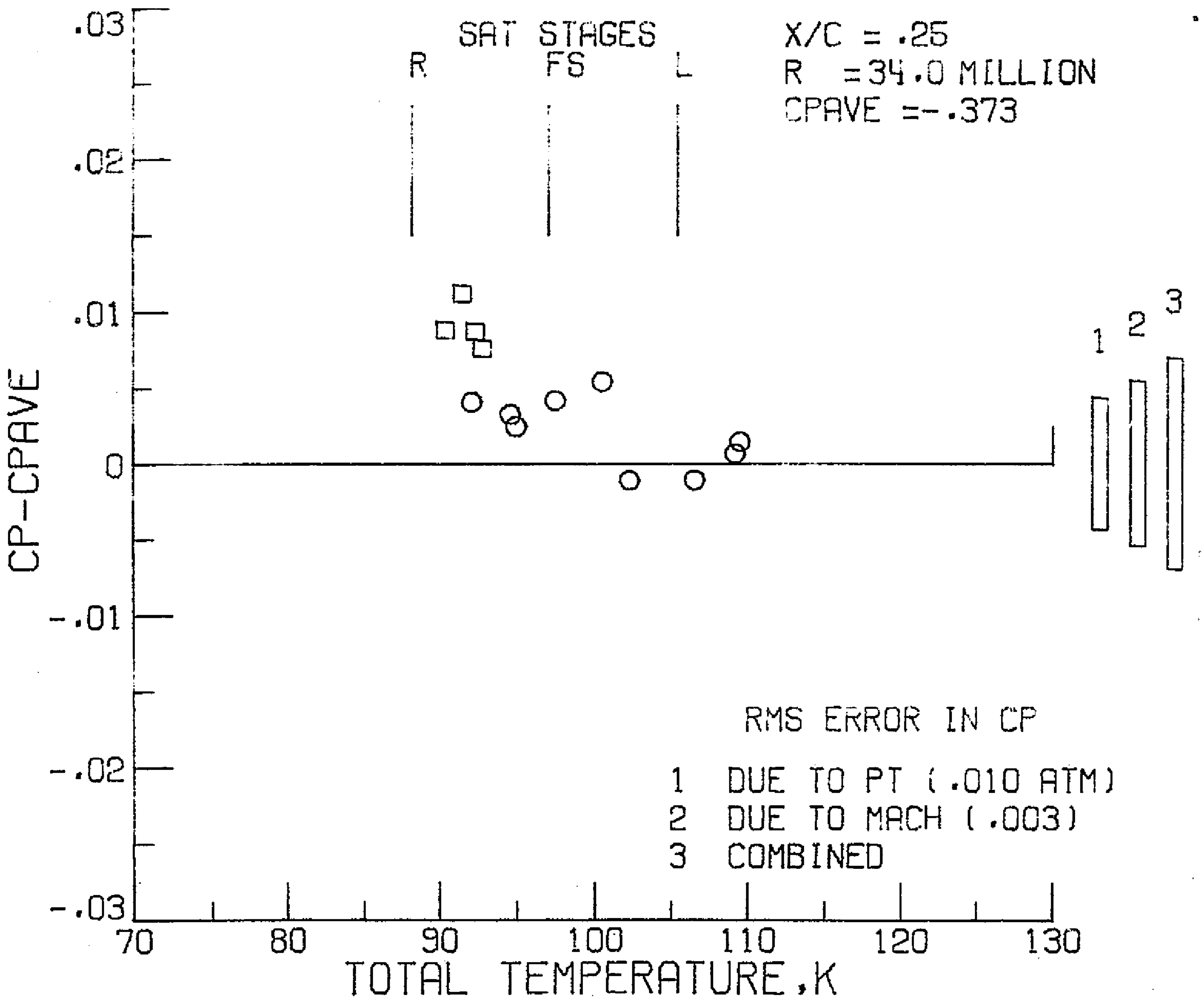


Figure 18. - Day 4 data not included.

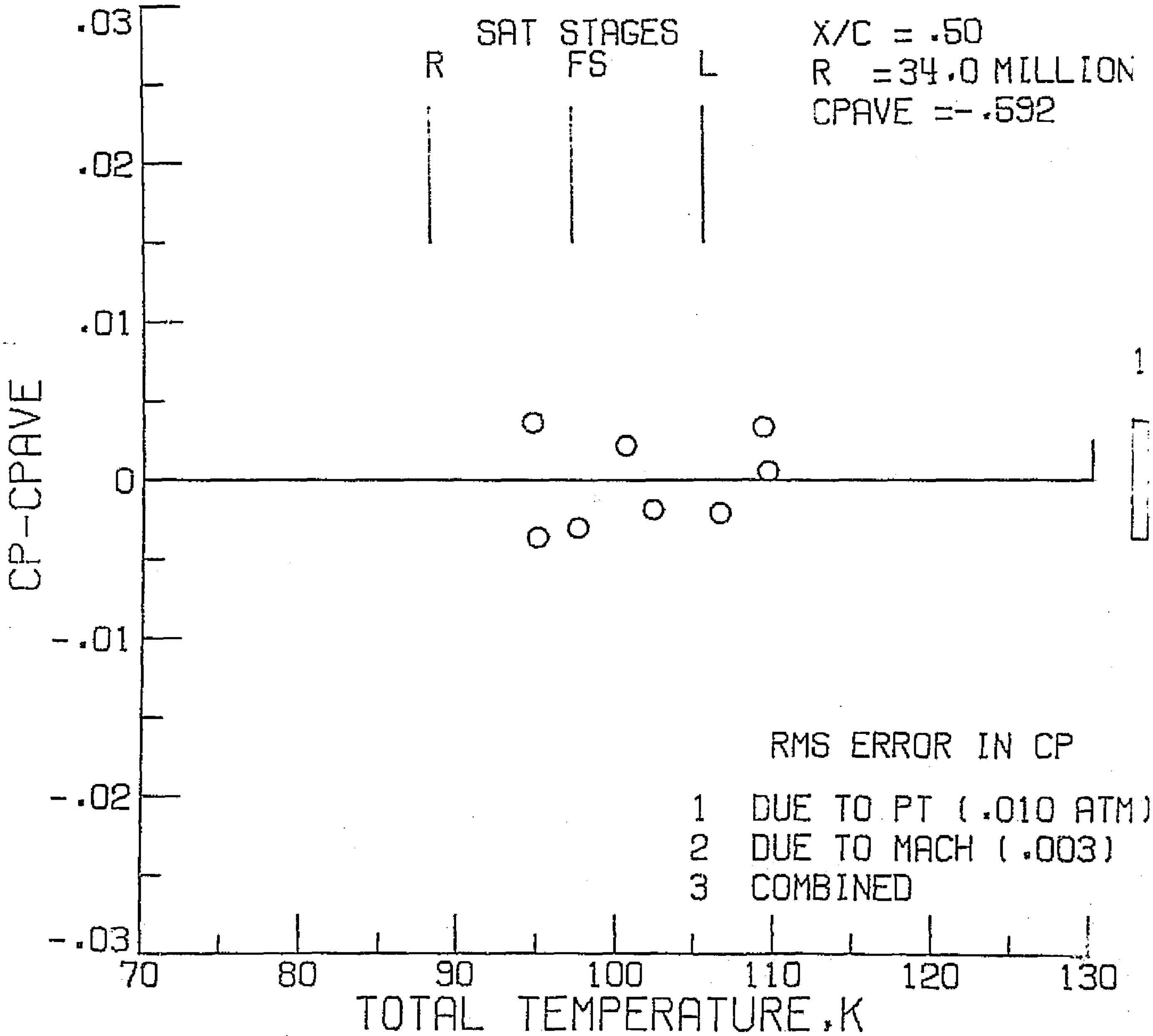


Figure 19. - Day 4 data not included.

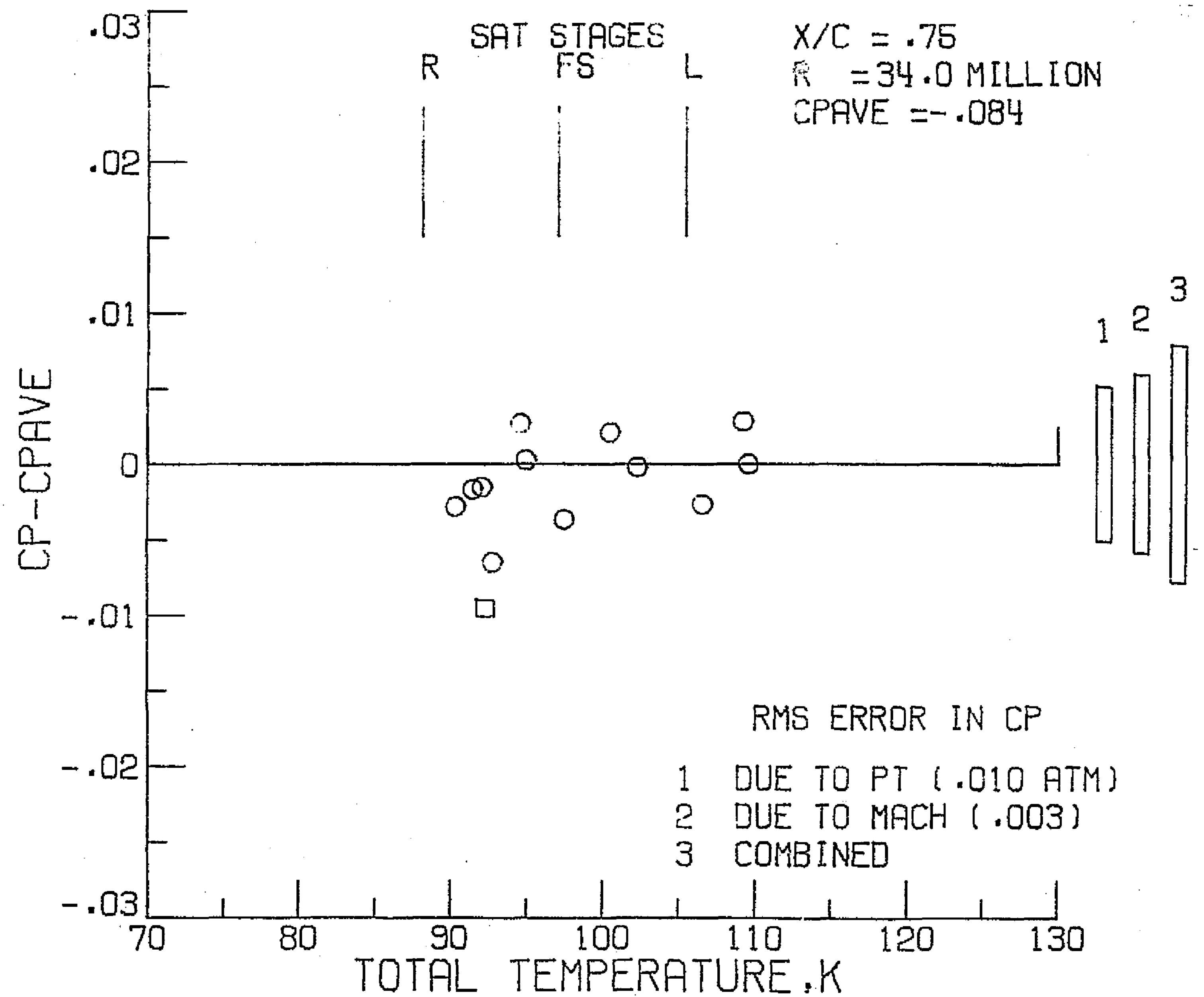


Figure 20. - Day 4 data not included.

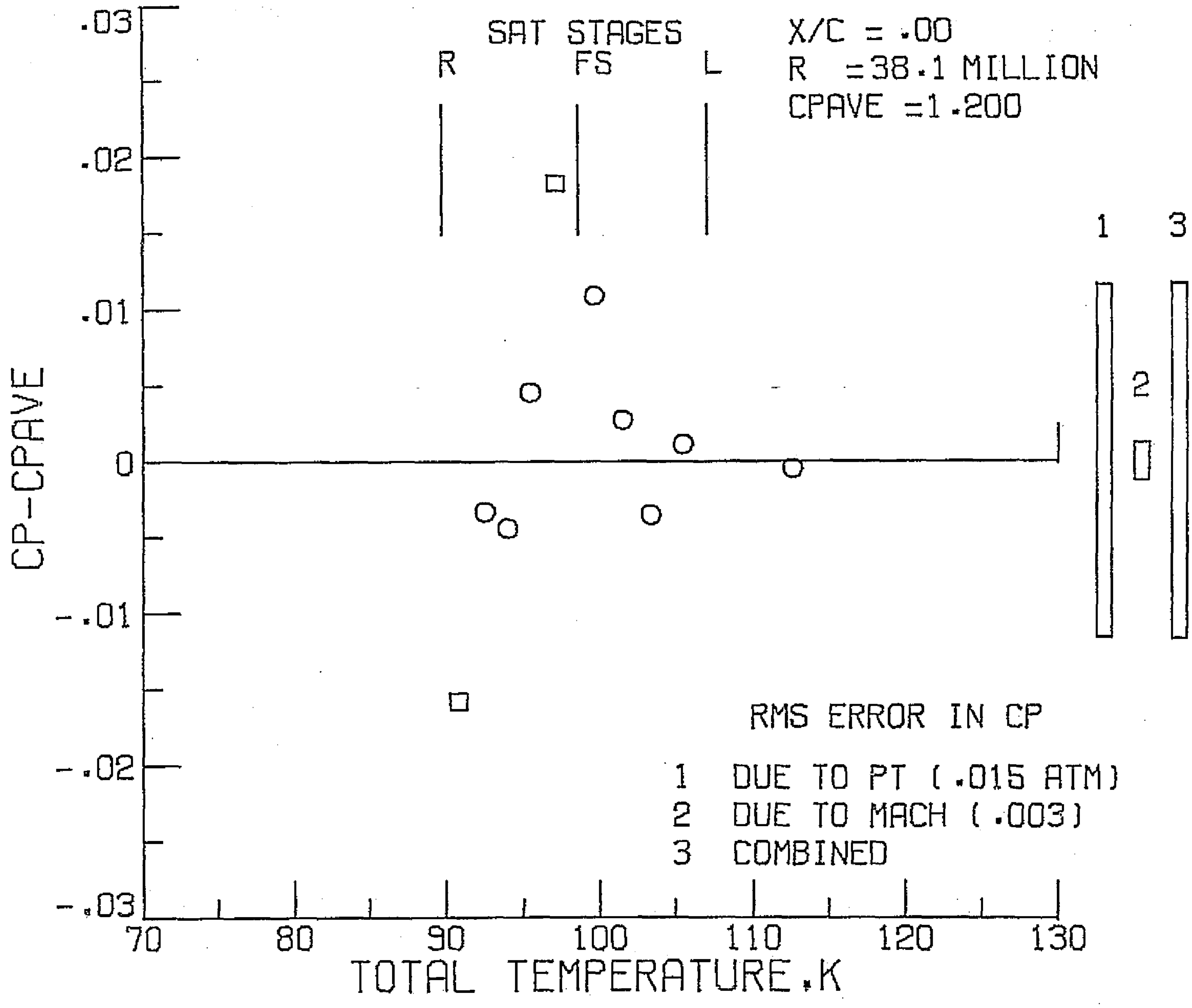

SAT STAGES
R
FS
L
X/C = .00
R = 38.1 MILLION
CPAVE = 1.200
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.015 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 21.

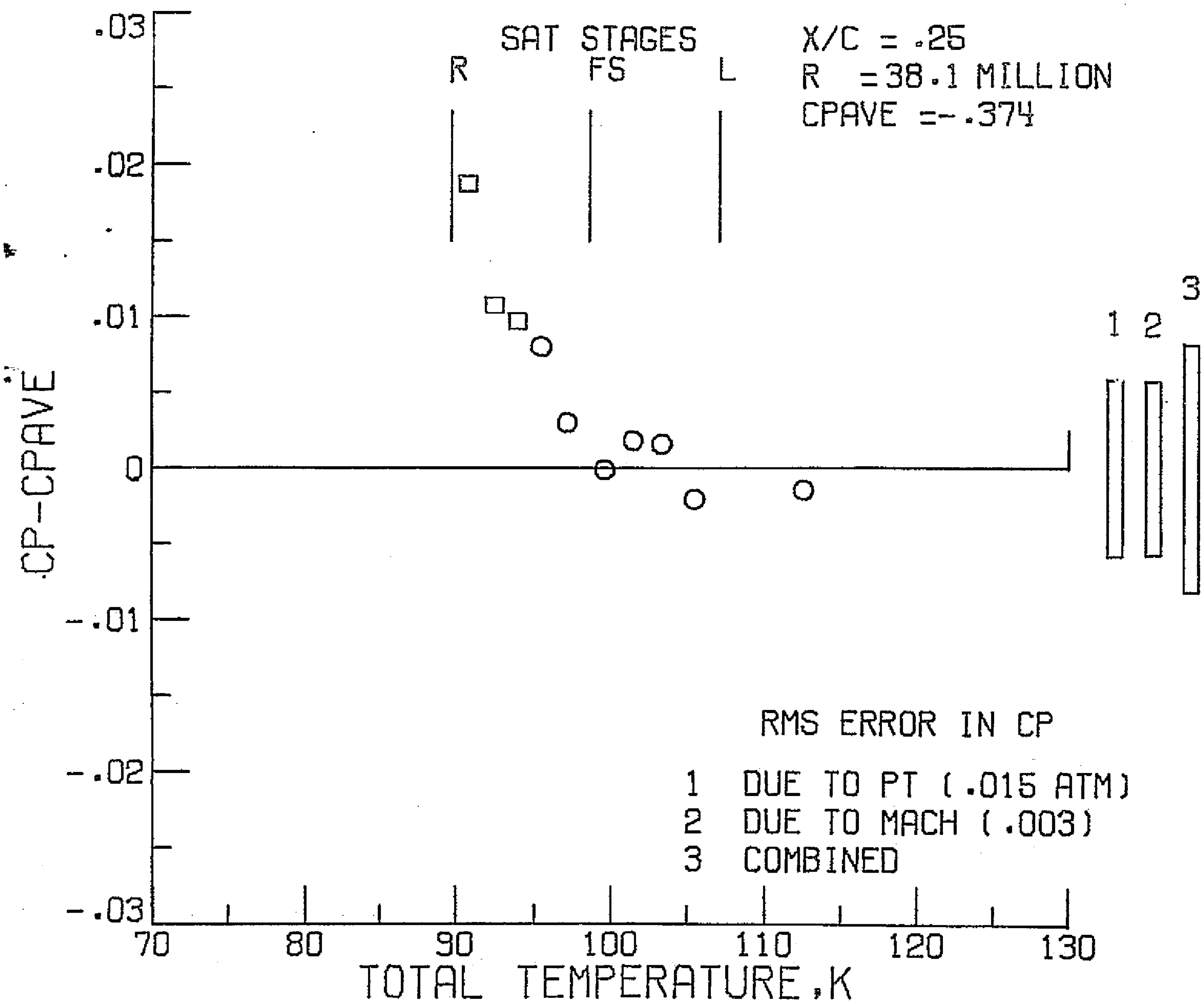

SAT STAGES
R
FS
L
X/C = .25
R = 38.1 MILLION
CPAVE = -.374
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.015 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE, K

Figure 22.

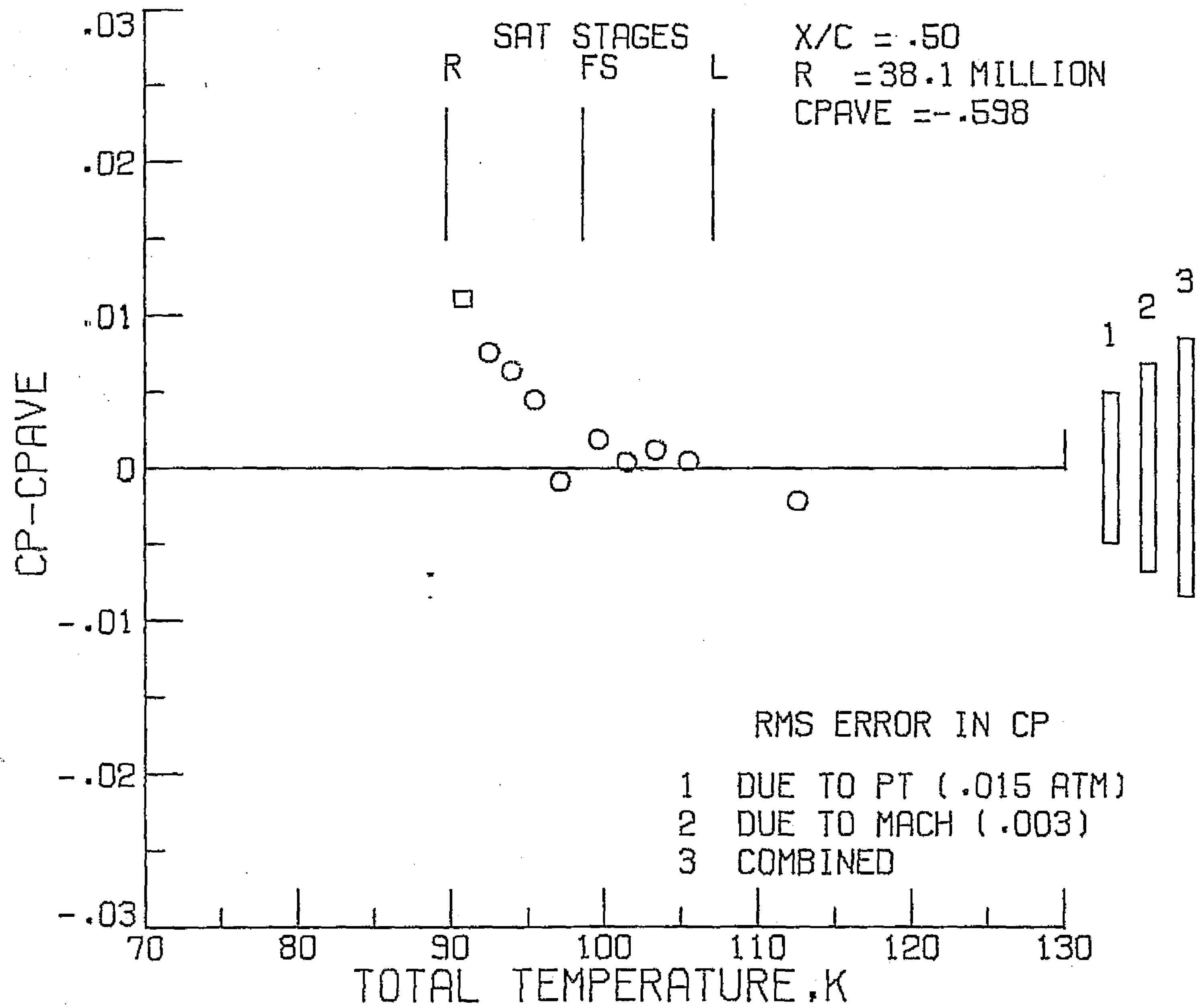
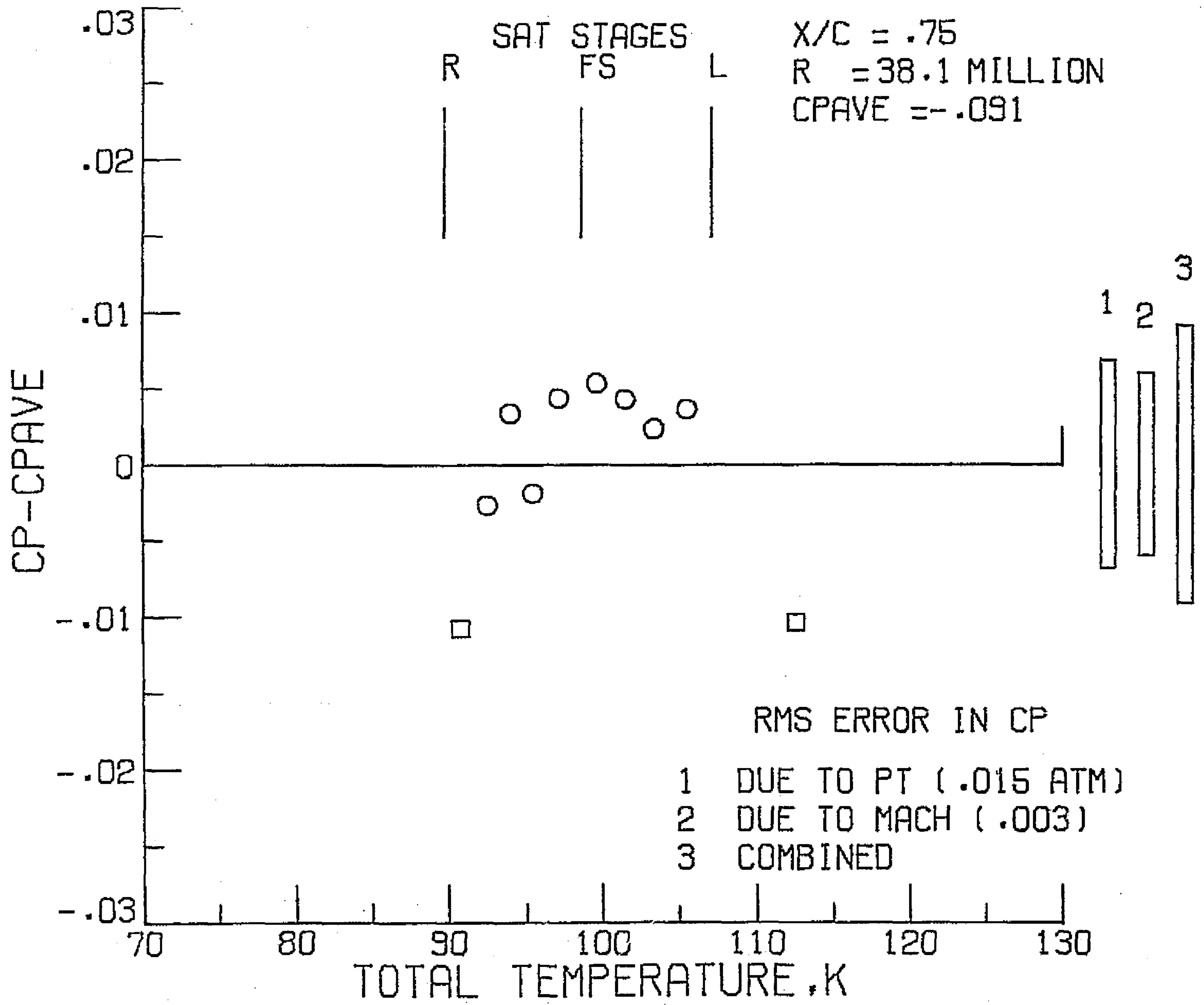

SAT STAGES
R
FS
L
X/C = .50
R = 38.1 MILLION
CPAVE = -.598
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.015 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 23.



SAT STAGES
R
FS
L
X/C = .75
R =38.1 MILLION
CPAVE =-.091
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.015 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 24.

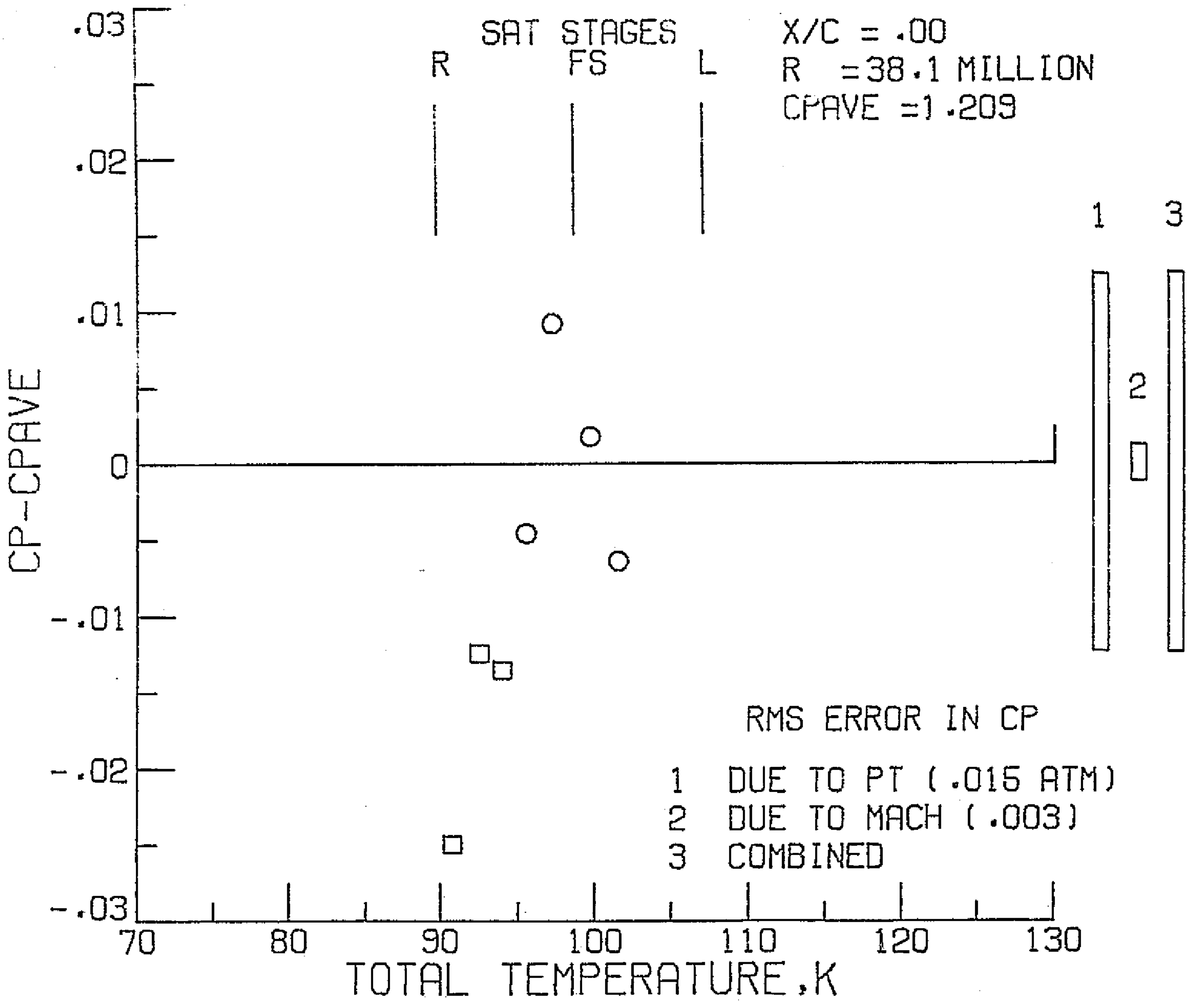


Figure 25. - Day 4 data not included.

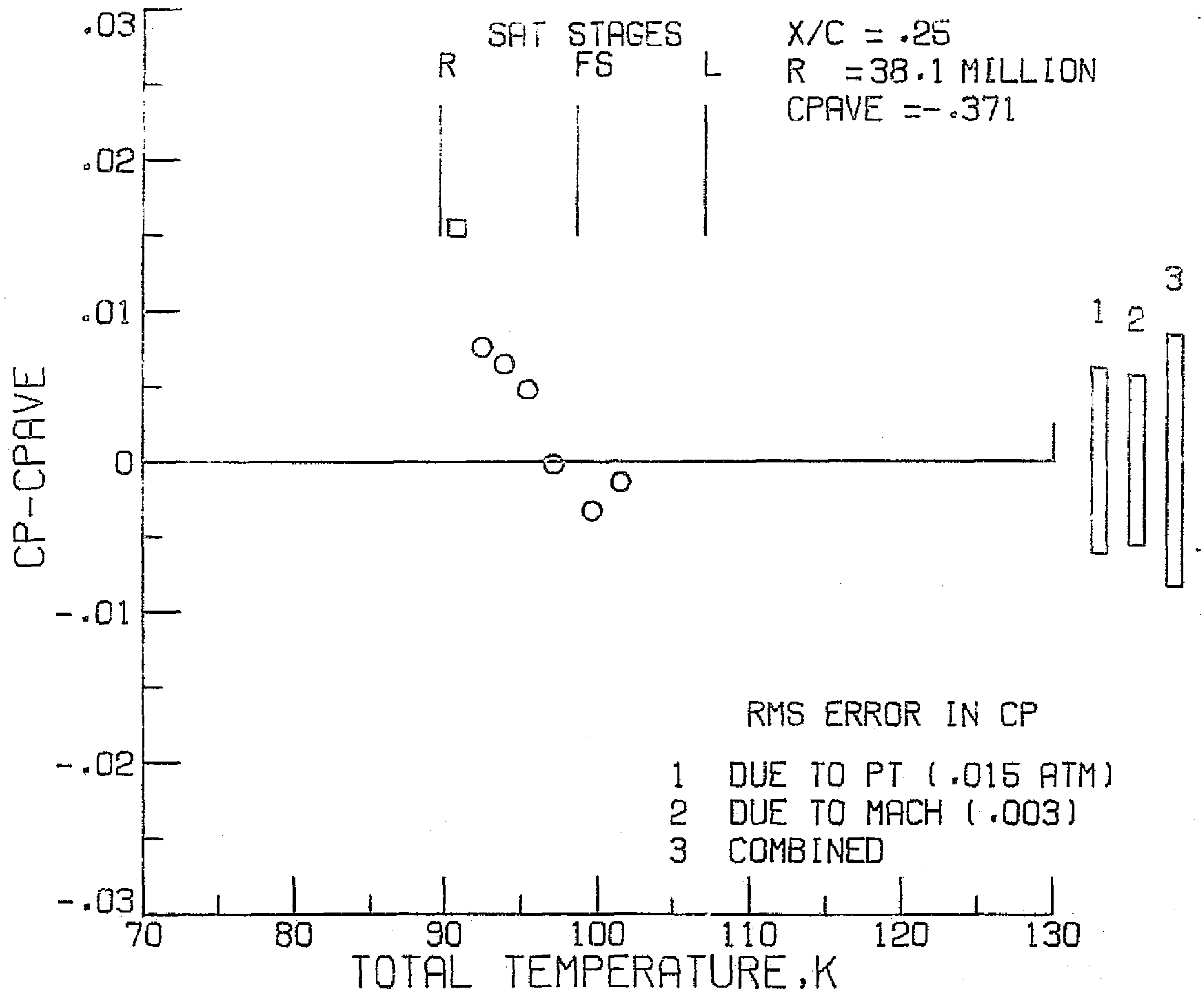


Figure 26. - Day 4 data not included.

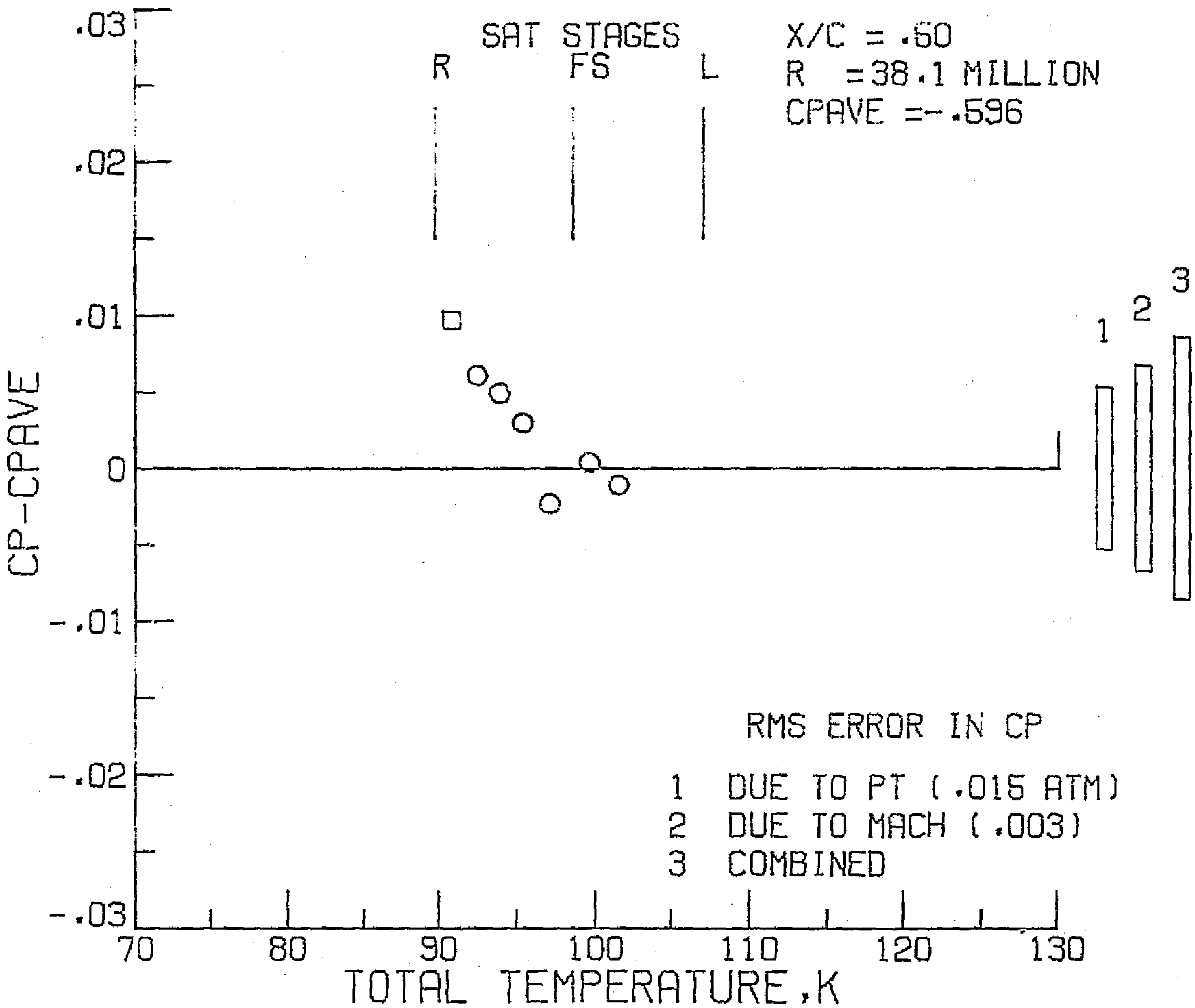


Figure 27. – Day 4 data not included.

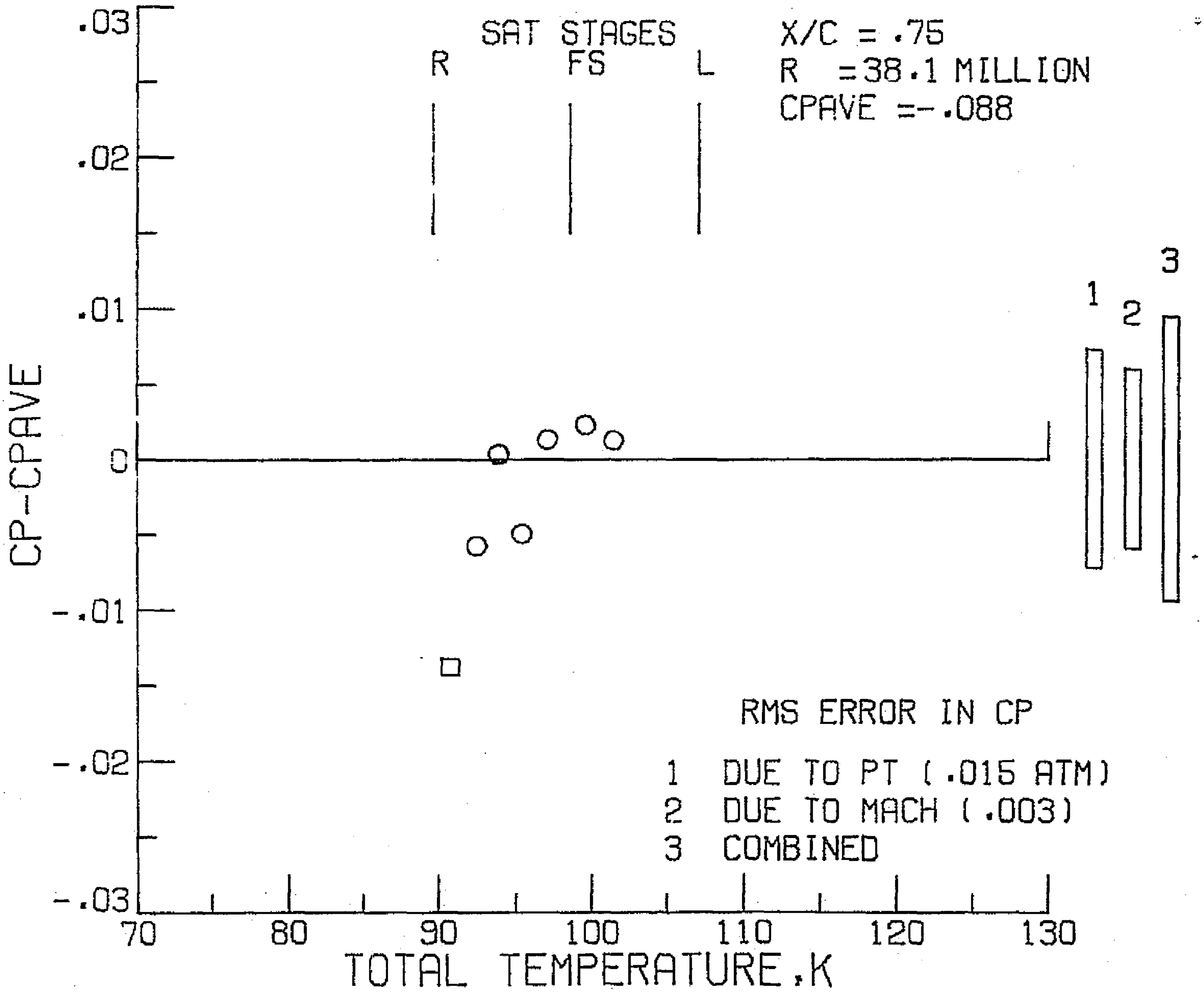


Figure 28. - Day 4 data not included.

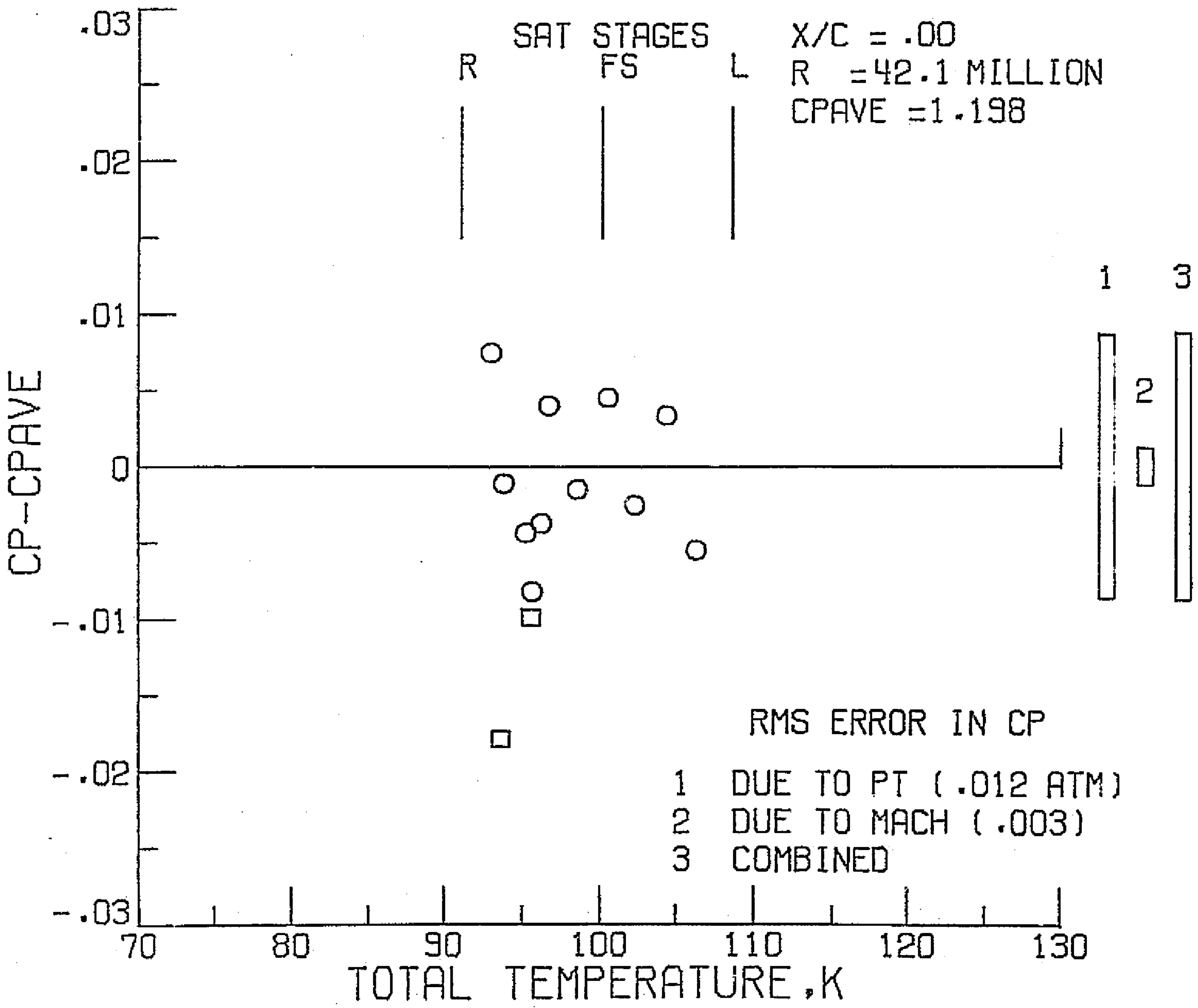
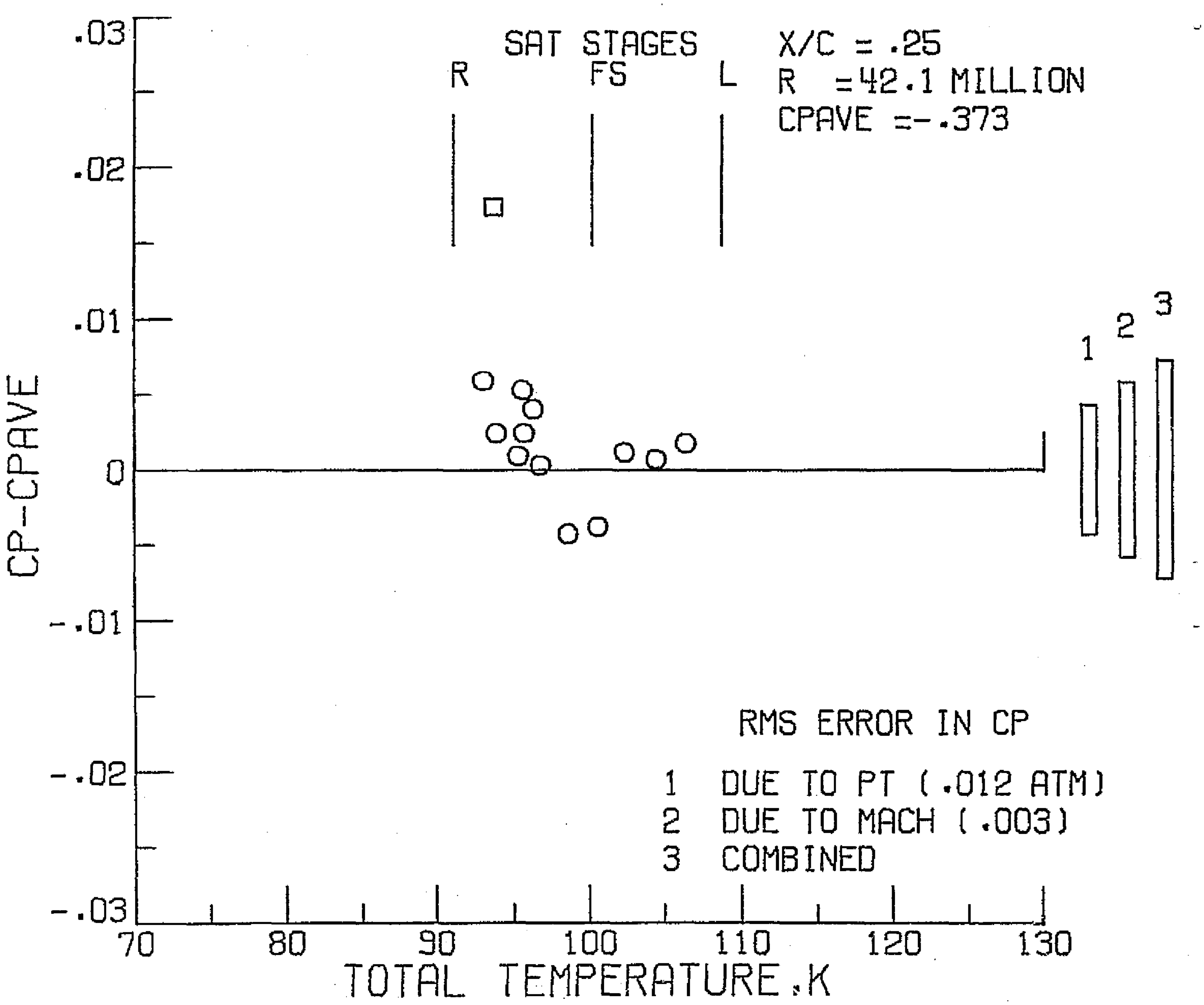

SAT STAGES
R
FS
L
X/C = .00
R =42.1 MILLION
CPAVE =1.198
1
2
3
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K
RMS ERROR IN CP
1 DUE TO PT (.012 ATM)
2 DUE TO MACH (.003)
3 COMBINED

Figure 29.



SAT STAGES
R
FS
L
X/C = .25
R =42.1 MILLION
CPAVE =-.373
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.012 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 30.

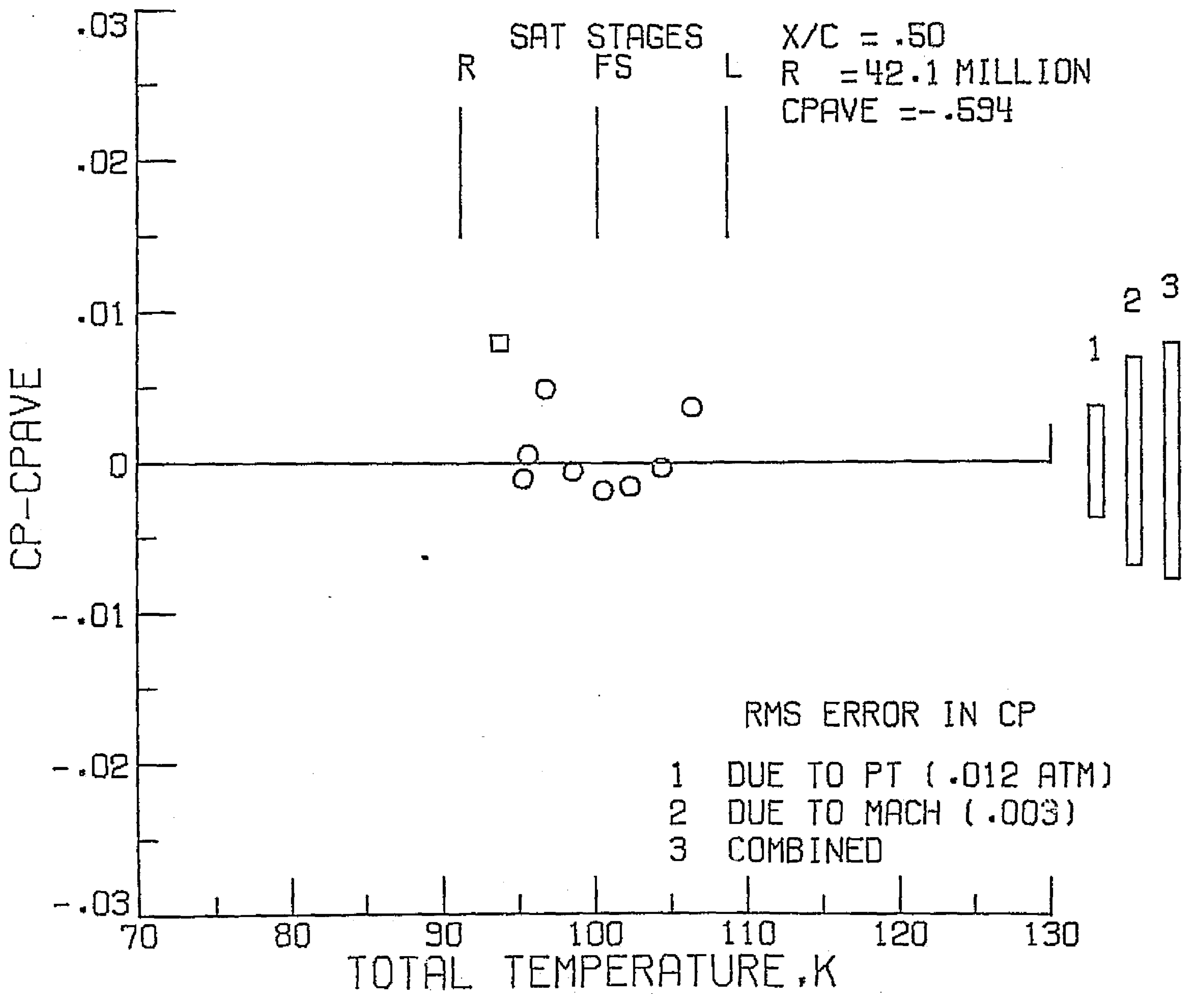
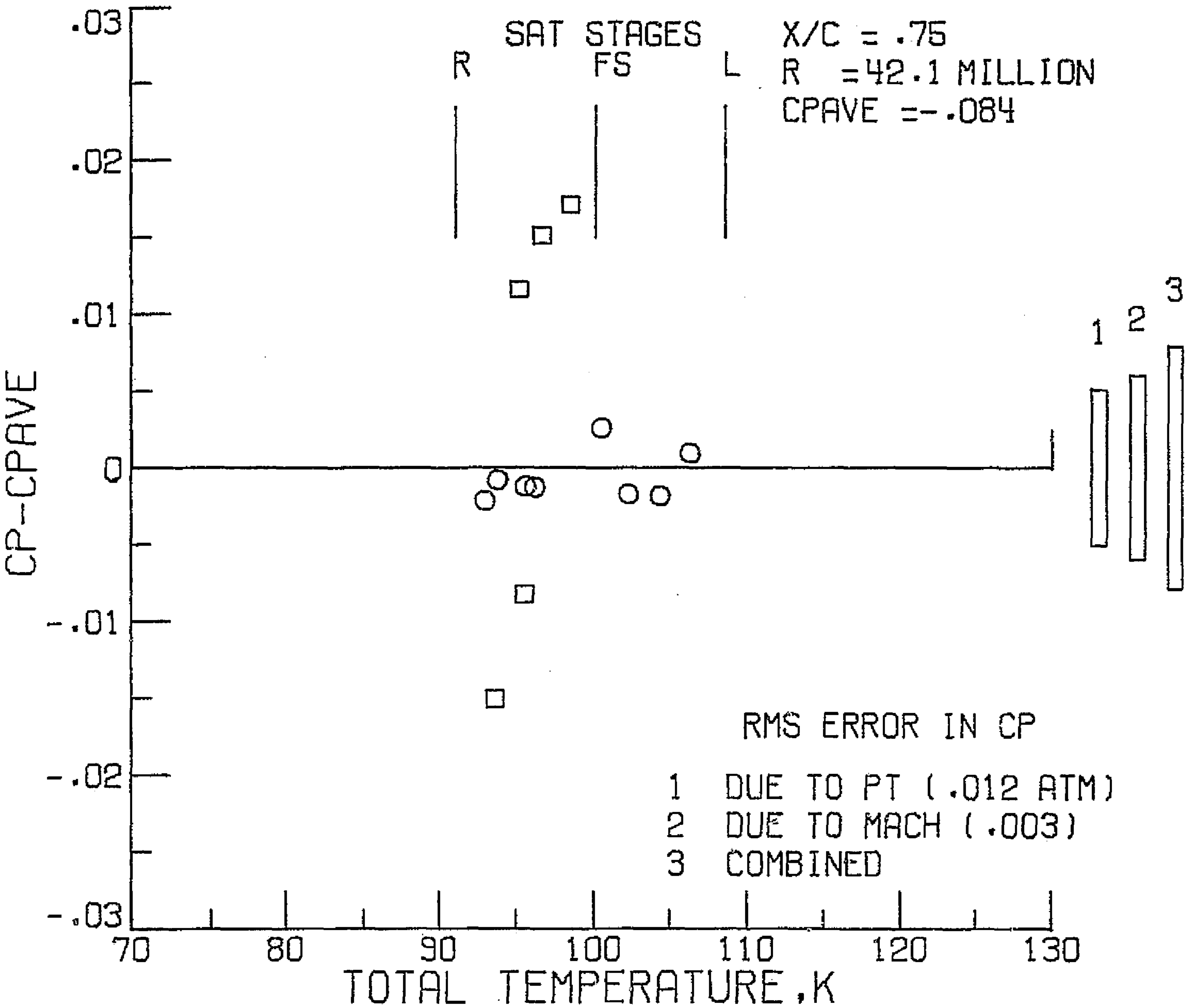

SAT STAGES
R
FS
L
X/C = .50
R =42.1 MILLION
CPAVE =-.594
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.012 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 31.



SAT STAGES
R
FS
L
X/C = .75
R =42.1 MILLION
CPAVE =-.084
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.012 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 32.

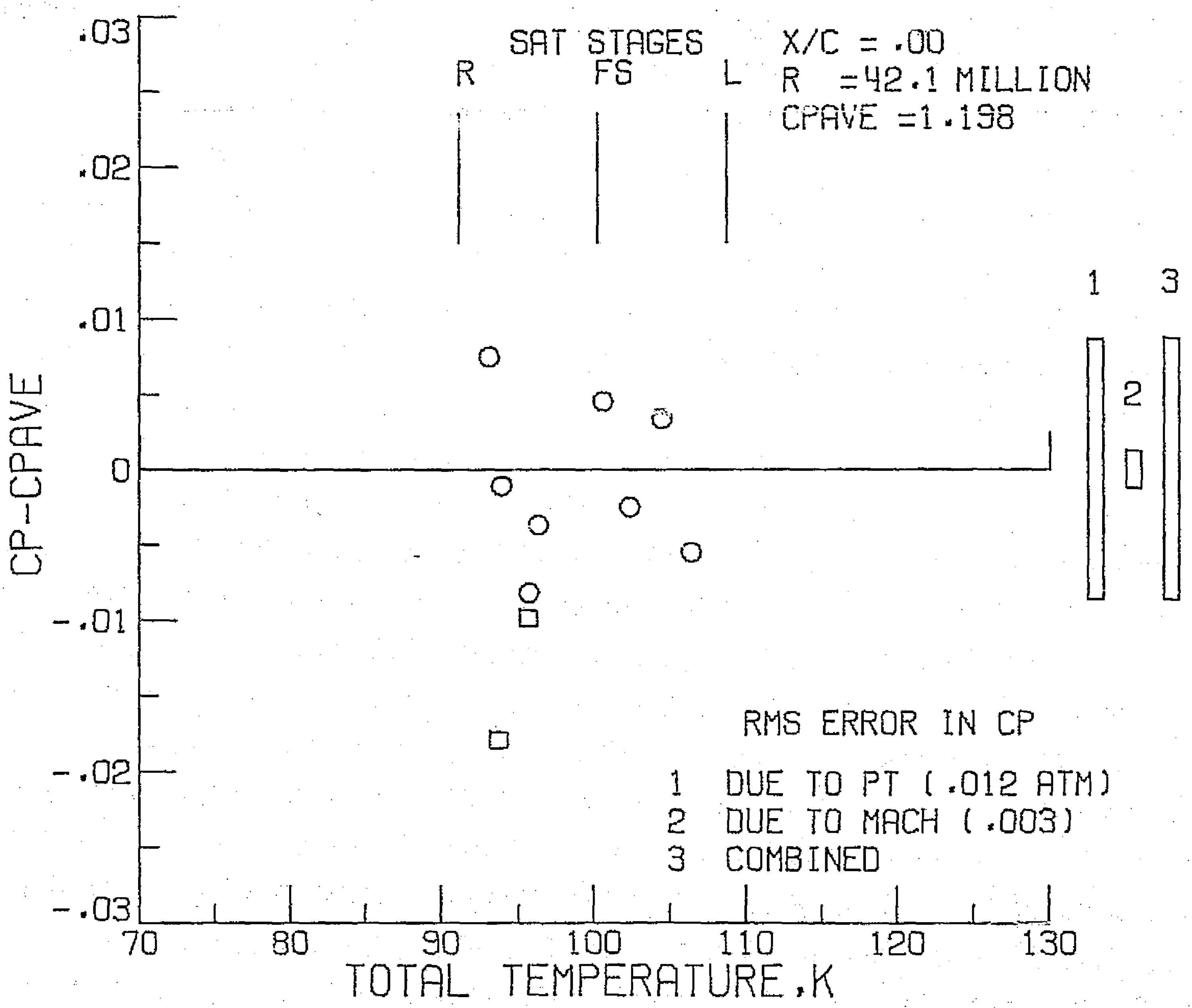


Figure 33. - Day 4 data not included.

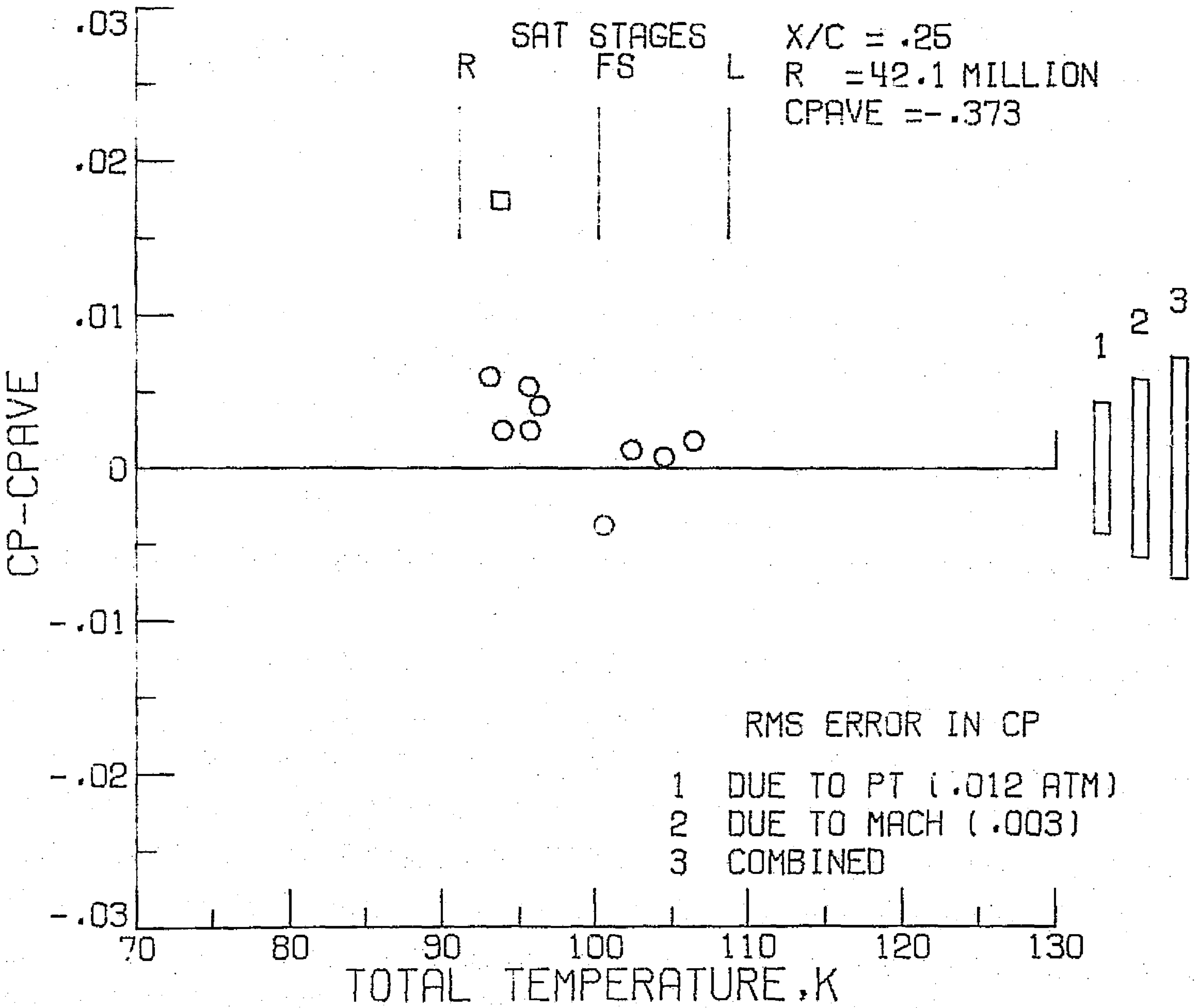


Figure 34. - Day 4 data not included.

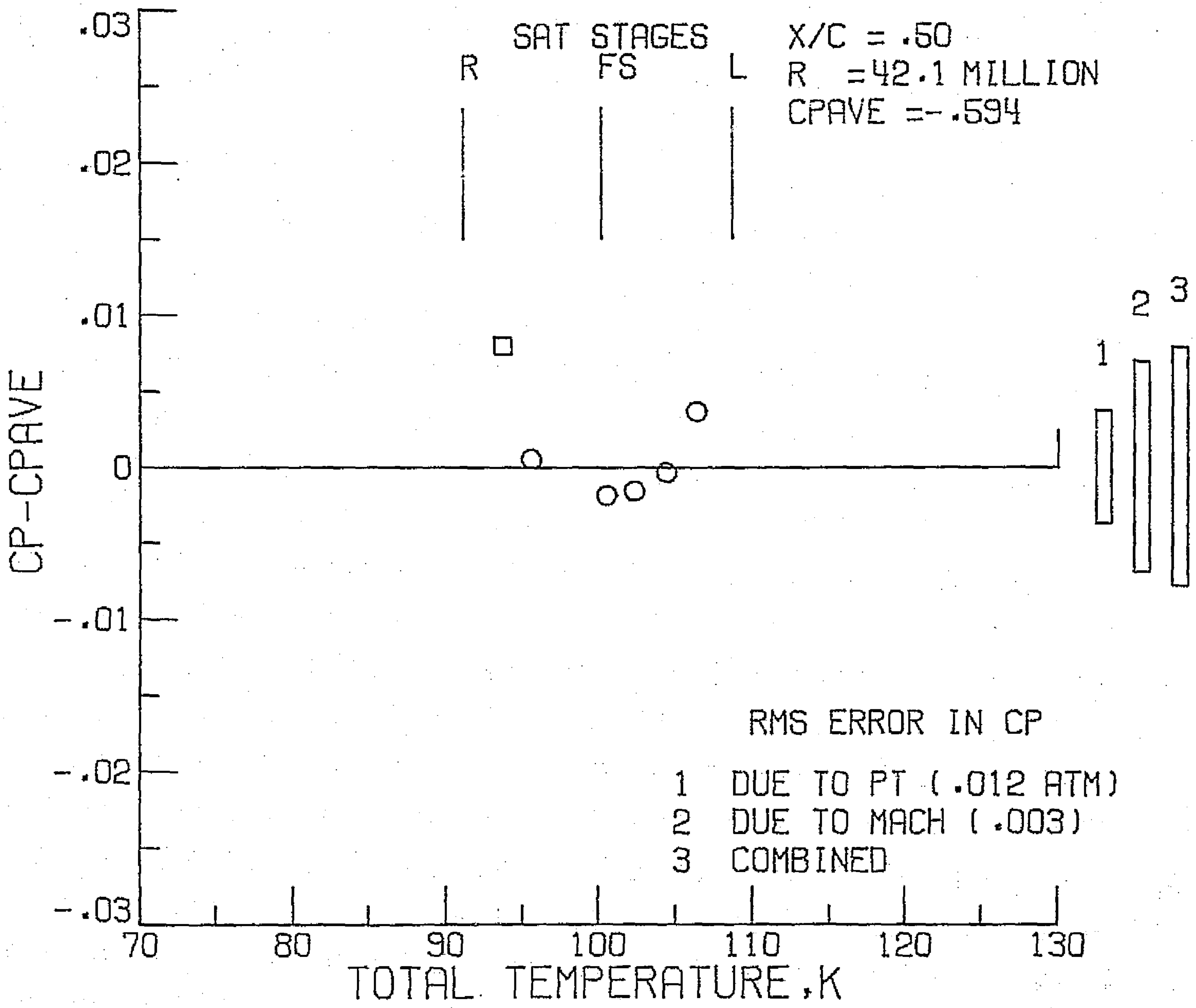


Figure 35. - Day 4 data not included.

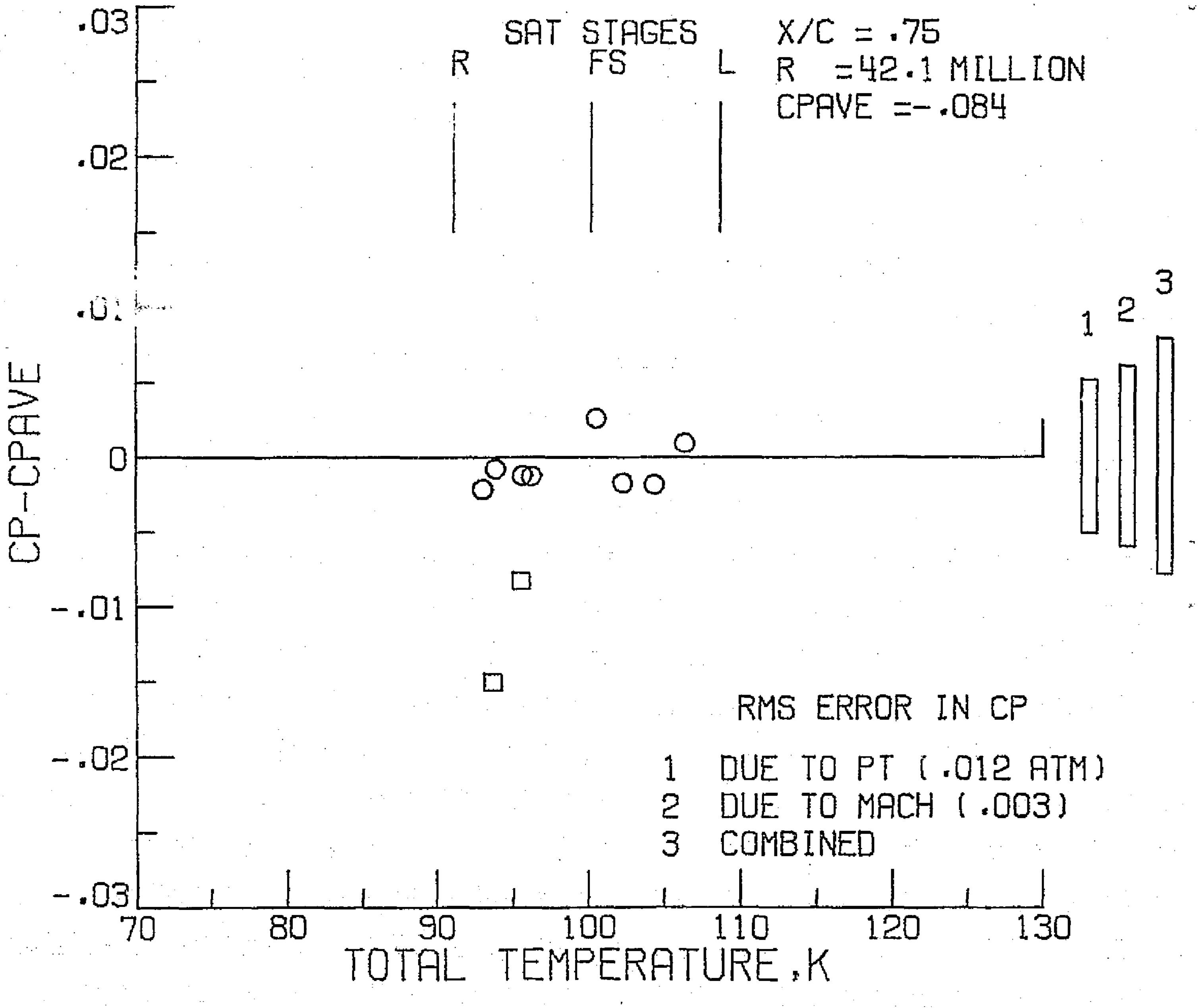
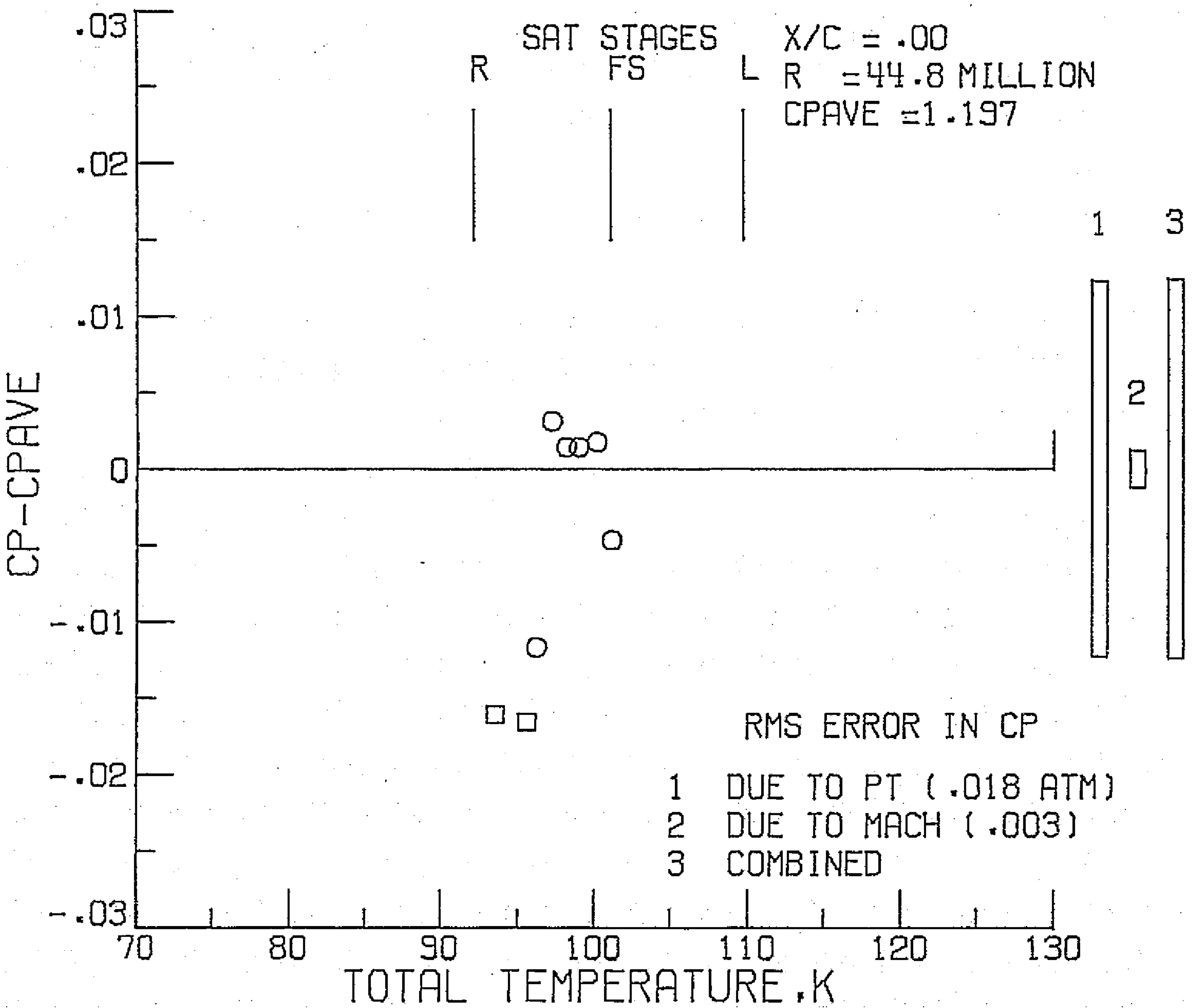
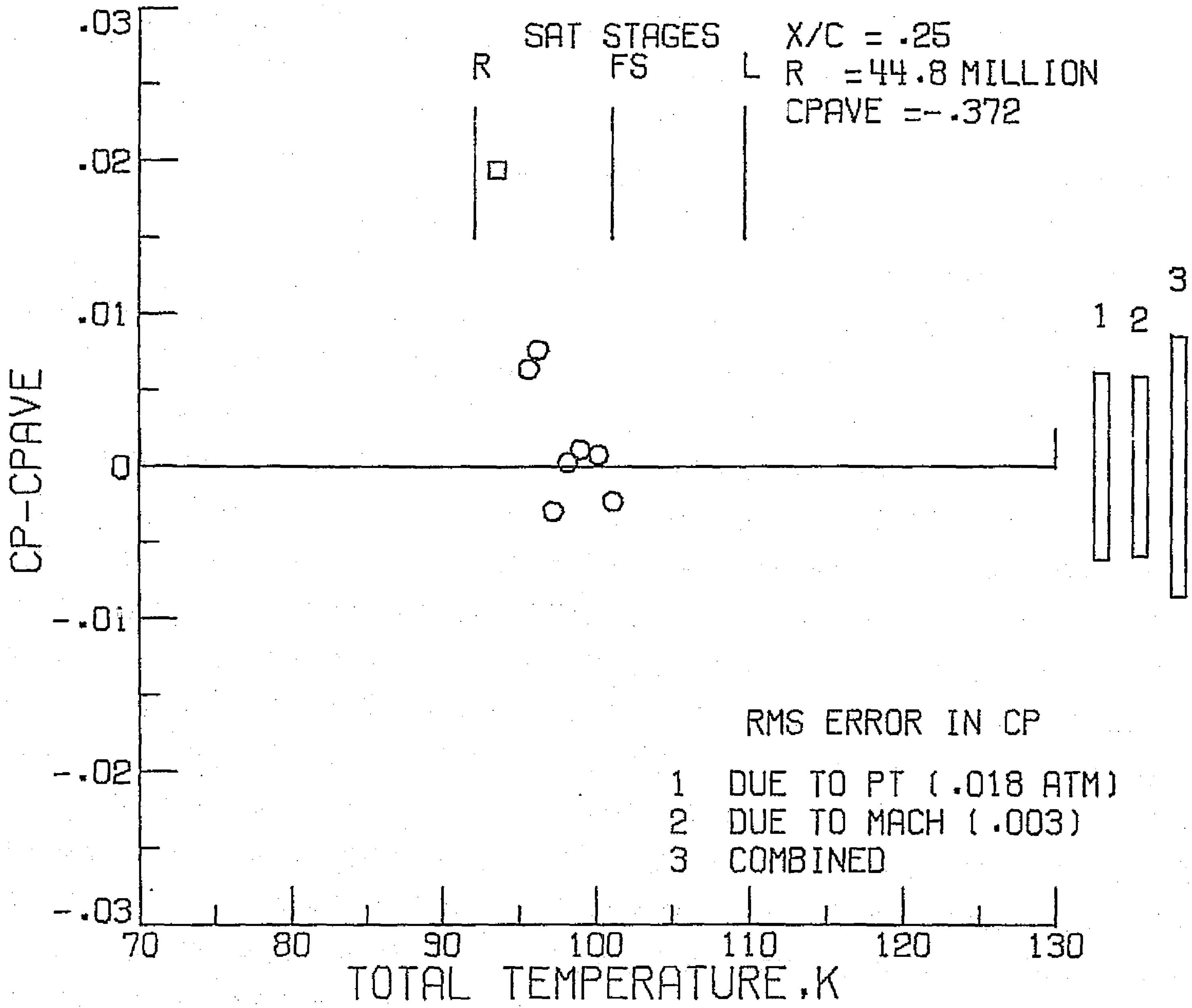


Figure 36. - Day 4 data not included.



SAT STAGES
R
FS
L
X/C = .00
R =44.8 MILLION
CPAVE =1.197
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.018 ATM)
2 DUE TO MACH (.003)
3 COMBINED
CP-CPAVE
.03
.02
.01
0
-.01
-.02
-.03
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 37.



SAT STAGES
R
FS
L
X/C = .25
R =44.8 MILLION
CPAVE =-.372
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.018 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 38.

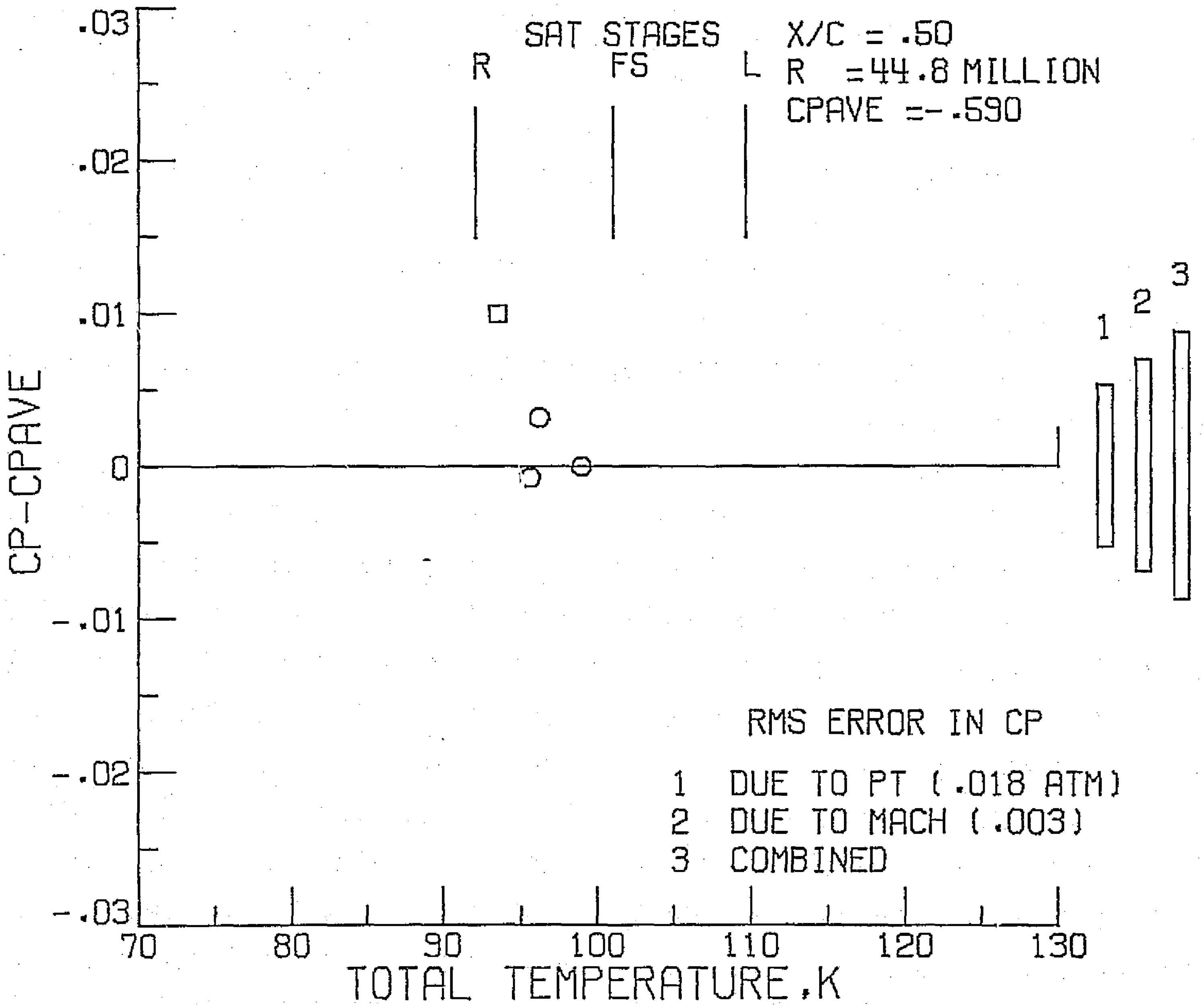


Figure 39.

Fig 39

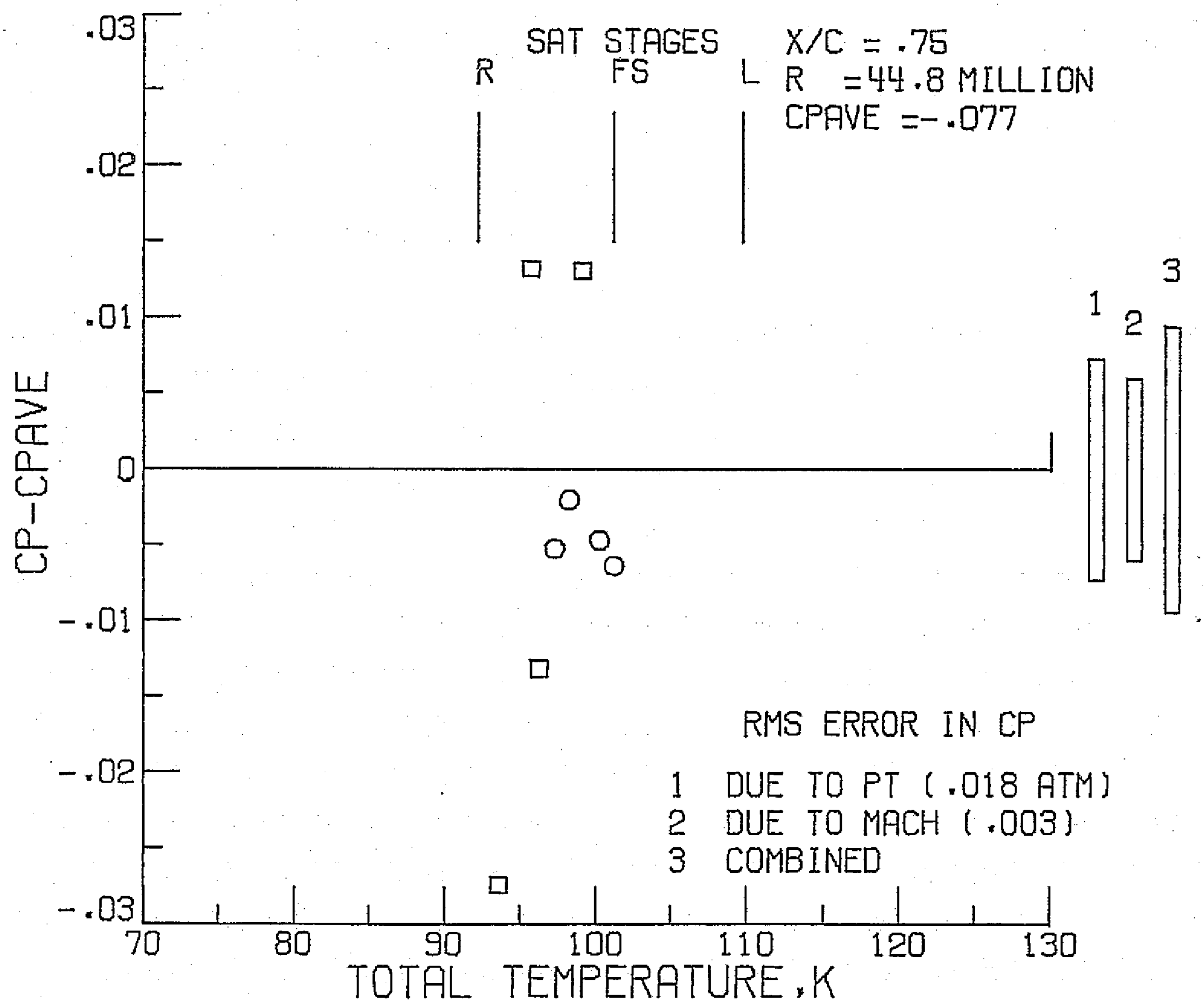

SAT STAGES
R
FS
L
X/C = .75
R =44.8 MILLION
CPAVE =-.077
.03
.02
.01
0
-.01
-.02
-.03
CP-CPAVE
1
2
3
RMS ERROR IN CP
1 DUE TO PT (.018 ATM)
2 DUE TO MACH (.003)
3 COMBINED
70
80
90
100
110
120
130
TOTAL TEMPERATURE,K

Figure 40.

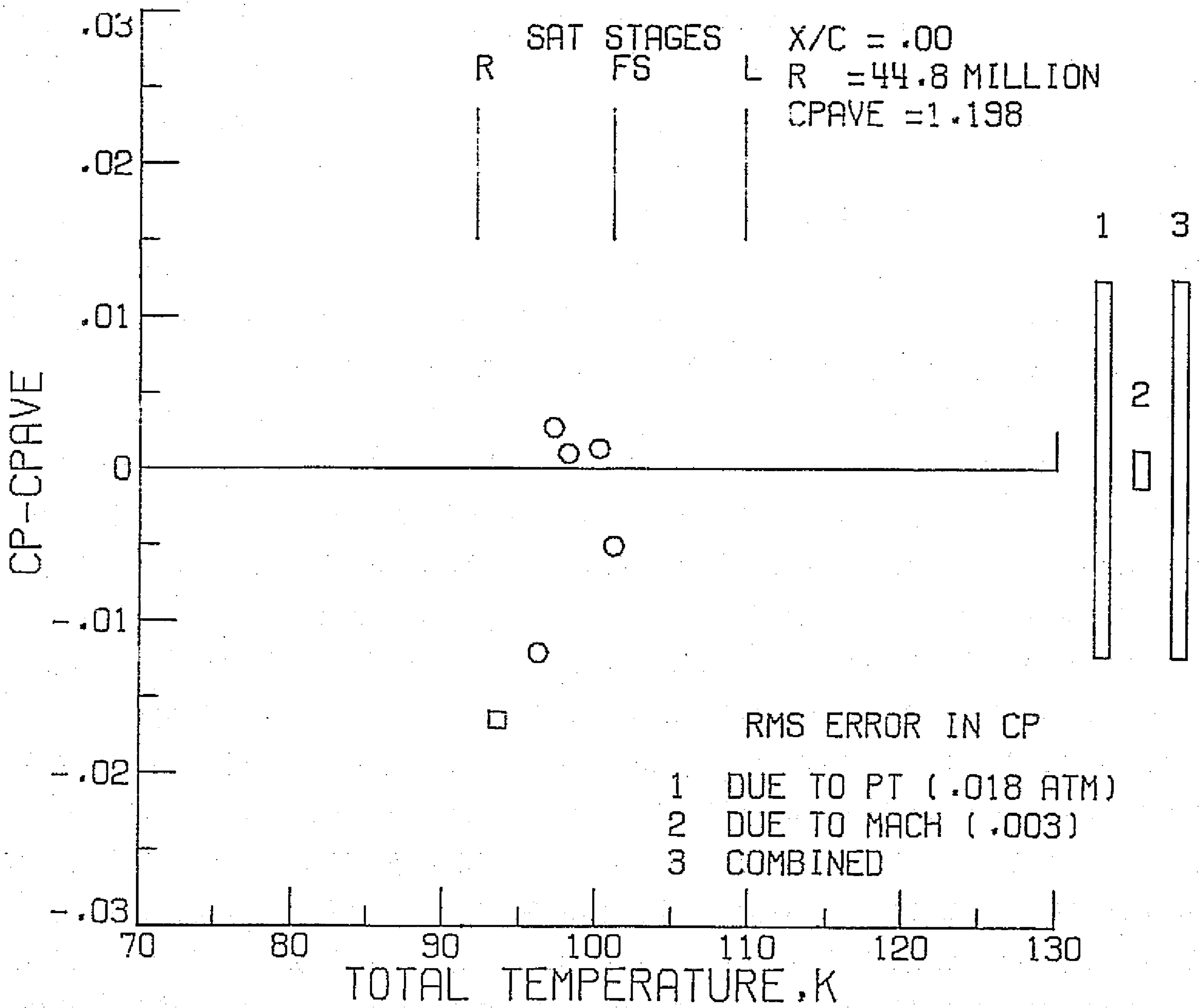


Figure 41. - Day 4 data not included.

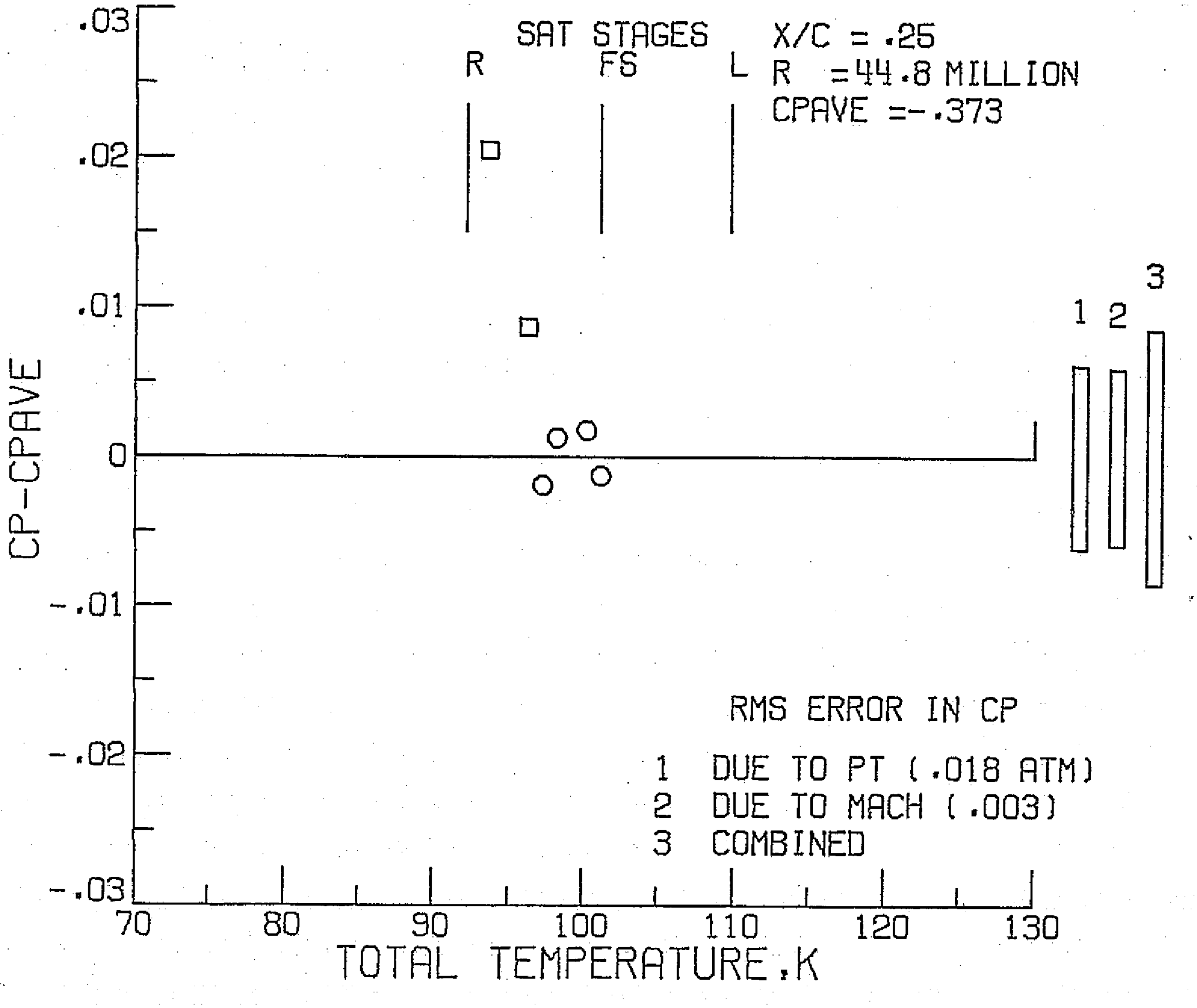


Figure 42. - Day 4 data not included.

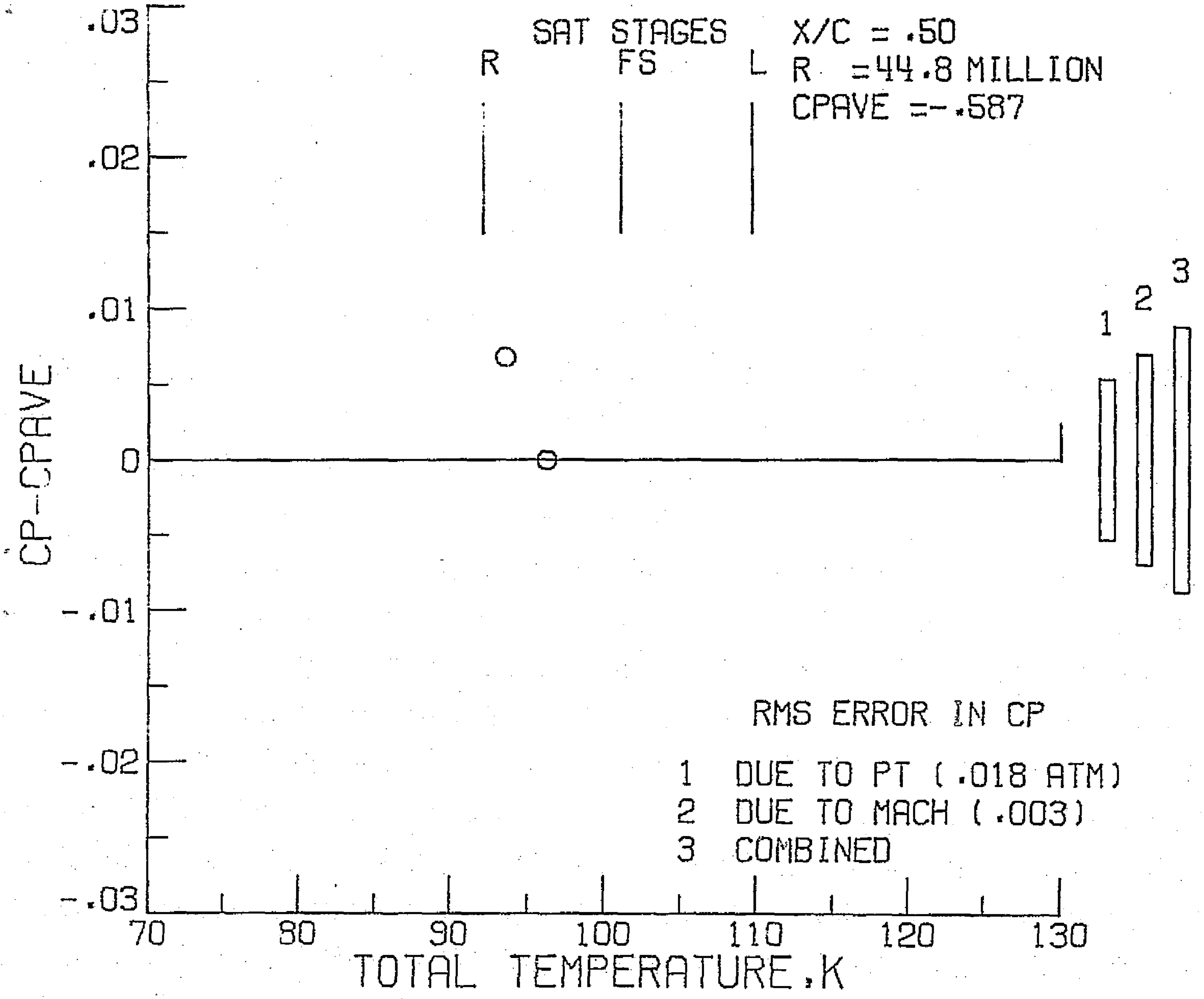


Figure 43. - Day 4 data not included.

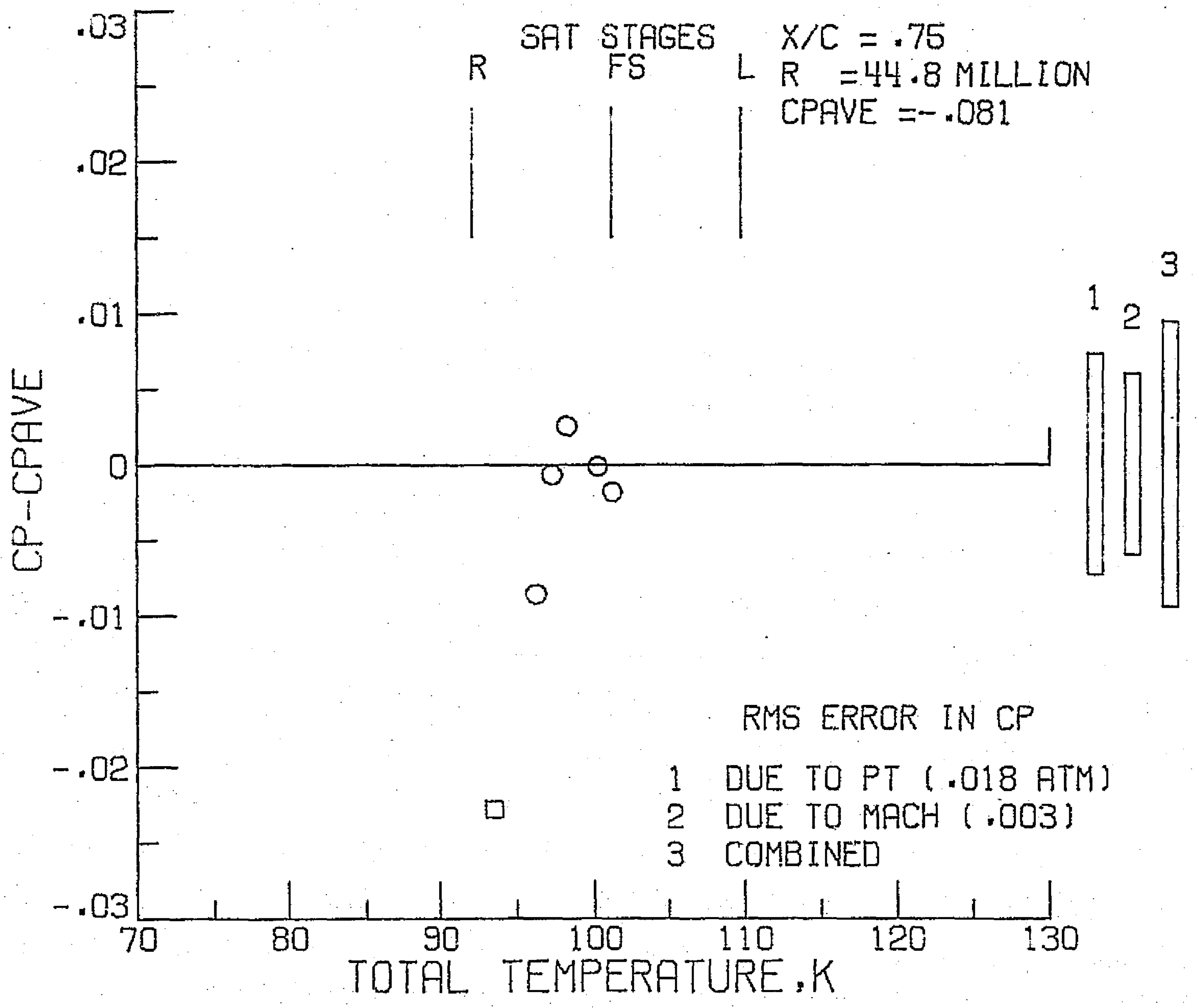


Figure 44. - Day 4 data not included.

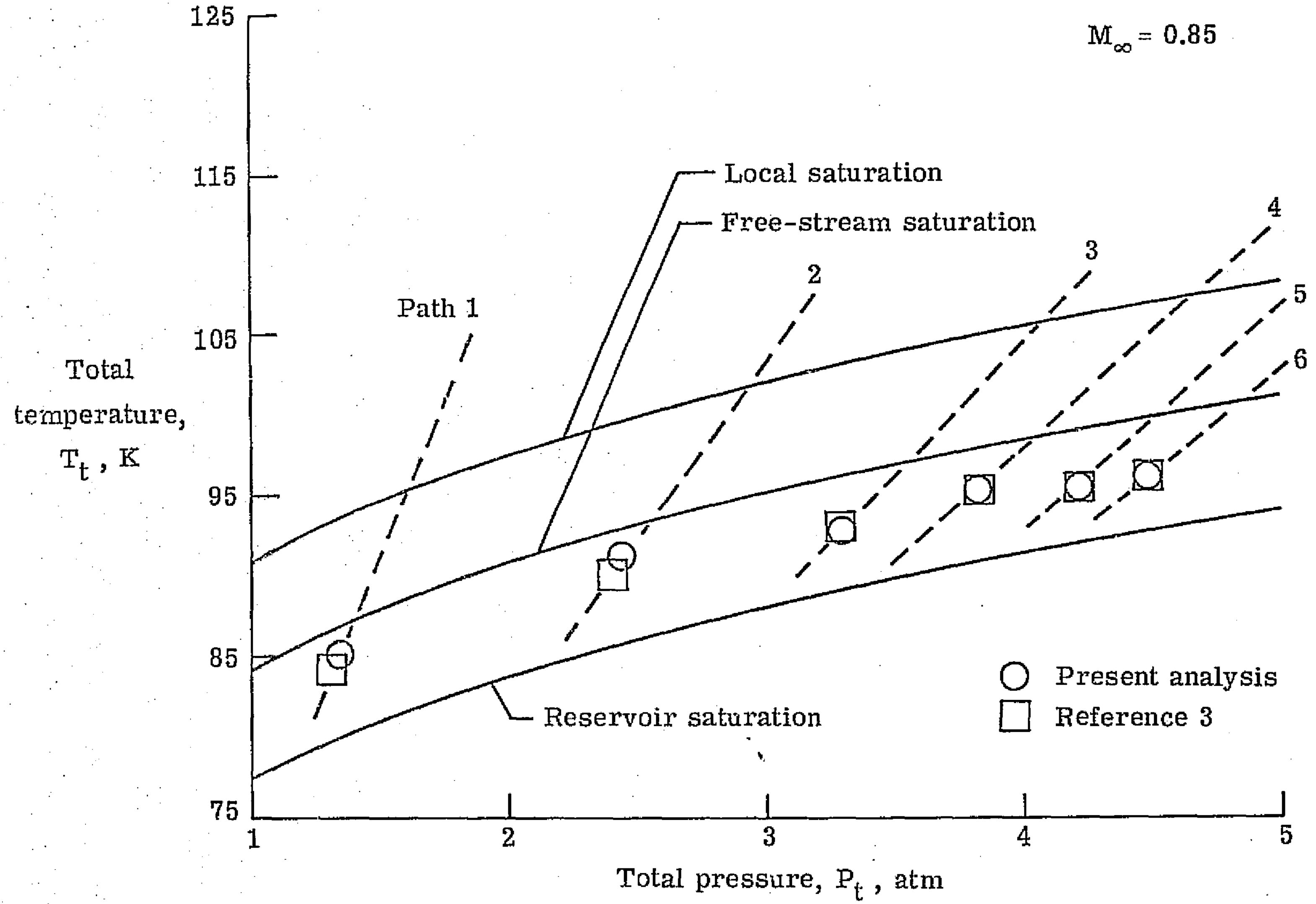


Figure 45. - Beginning of "possible" effects.
Reference 3 points shown for comparison.

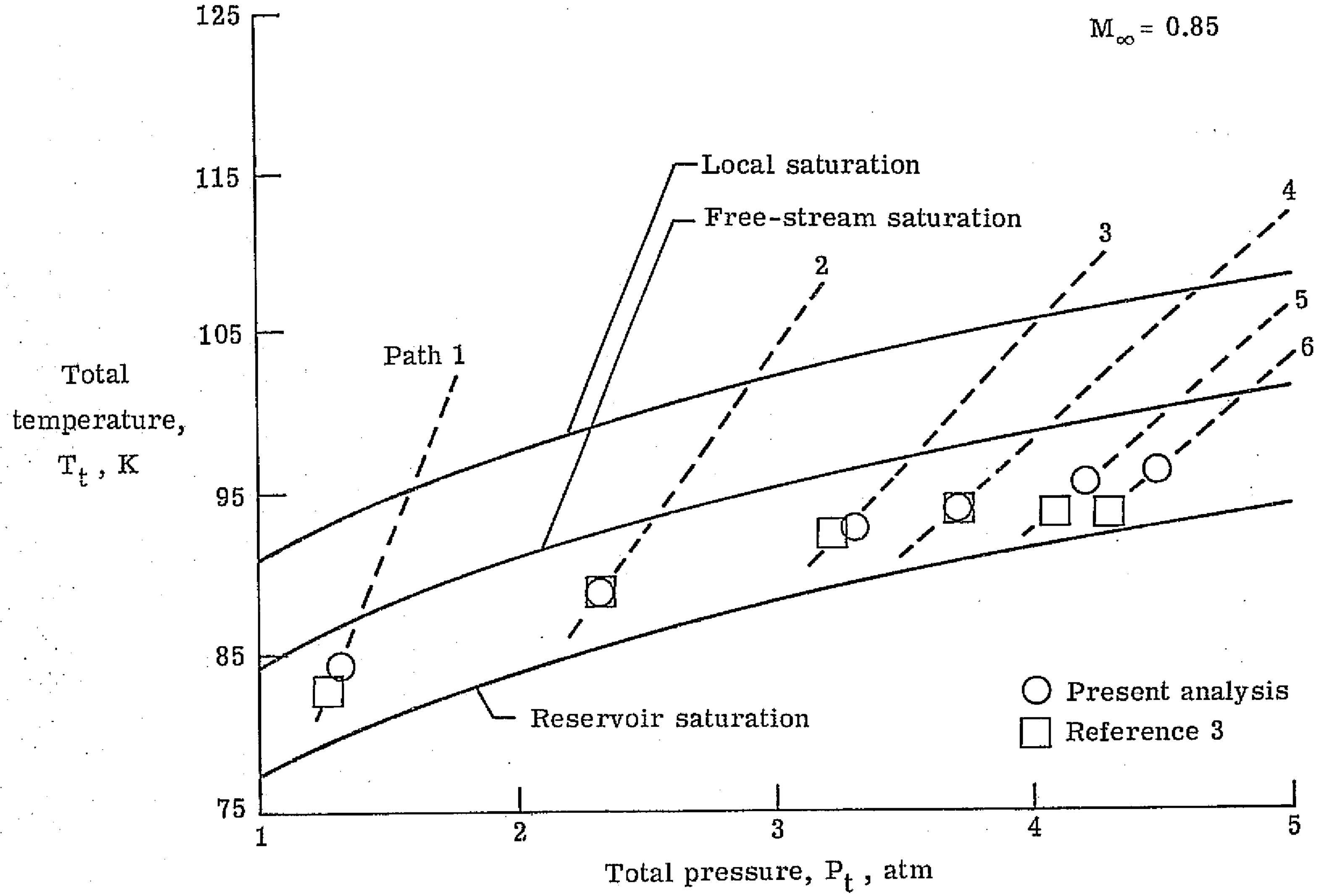


Figure 46. - Beginning of "definite" effects. Reference 3 points shown for comparison.