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Tropospheric - Stratospheric Measurement Studies Summary

Stuart W. Bowen

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TROPOSPHERIC-STRATOSPHERIC MEASUREMENT STUDIES

1998-1999

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INTRODUCTION

The two high altitude aircraft, ER-2 NASA #706,709 and the DC-8 NASA #717 are in active use in several programs of upper atmospheric research to study polar ozone changes, stratospheric - tropospheric exchange processes and atmospheric effects of aviation aircraft. The ER-2's have participated in seven major missions; STEP (1986- 1987), AAOE (1987), AASE (1989), AASE II (1992), SPADE (1992-1993), ASHOE/MAESA (1994), STRAT (1995) and POLARIS (1997) These expeditions mainly concentrated on vortex dynamics and the large losses of Ozone in the Polar regions (Ozone hole) observed in the spring, with SPADE verifying the complex dynamical chemical and physical processes that occur during sunrise and sunset, STRAT designed to obtain background measurements using the full ER-2 suite of instruments, and POLARIS (1997) to understand the mid-latitude and Arctic Ozone losses during the Northern Summer. The DC-8 with the MMS has participated in the SUCCESS (1996) and the SONEX (1997) missions.

The Meteorological Measurement System (MMS) with its sophisticated software accurately measures ground speed and attitude, in-situ static and dynamic pressure.total temperature, which are used to calculate the three dimensional wind fields, static pressure, temperature and turbulence values to meteorological accuracy. The meteorological data is not only of interest for its own sake in atmospheric dynamical processes such as mountain waves and flux measurements; but is also required by other ER-2 experiments that simultaneously measure water vapor, O_3, aerosols, NO, HCl, CH_4, N_2O, ClO, BrO, CO_2, NOy, HOx and temperature gradients. MMS products are extensively used to assist in the interpretation of their results in understanding the importance of convective effects relative to in-situ chemical changes, as may be noted by examining the list of references attached.

The MMS consists of three subsystems:

(a) aircraft instrumentation, inertial navigation system (INS), static and dynamic pressure taps,

(b) additional dedicated instrumentation measuring angle of attack, yaw, total temperature, and a GPS which on the DC-8 measures position, velocity and attitude

(c) an on board data, storage and computing acquisition system.

This instrumentation and the associated software requires both an on-going laboratory ground calibration procedure for the total air temperature, static and total pressure inputs, verification of the INS dynamic response and also extensive air measurements and intercomparisons which ultimately verify and calibrate the complete system and its software. More than the usual accuracy is required because of the near cancellation occurring in the difference between the ground speed and true airspeed vectors used to give the wind vector.

In the past year we have redesigned, recalibrated and used the MMS system on the NASA DC-8 that was previously used in the SUCCESS mission for the SONEX mission

I participated in SONEX, attending a planning meeting at Goddard SFC in June 1997 and flying on the DC-8 in support of its checkout flights, the transit flights, and many of the local data flights. The SONEX mission left Ames in Oct 1997, touched down at Bangor Maine, then onto Shannon Ireland for several local flights, then to the Azores for one local flight, back to Bangor for local flights and finally home to Ames toward the end of November. (18 flights, 112 hrs in the air)

Two papers were written with coauthors, based on the SUCCESS flights, one on mountain waves, one on our new turbulence measurements. Both papers were peer reviewed, extensively revised and accepted for publication in GRL.

Several reports and handouts were written for SONEX. These included a **MMS Maneuvers or** *Why We Suffer,*, written to explain the necessity of our maneuvers to the experimenters, **MMS DC-8 Calibration Maneuvers SONEX** given to the pilots to explain just what we required, and a set of **MMS Wiggle Curves** that showed the ± excursions for our maneuvers as we were flying in the controlled track system over the North Atlantic.

Calibration of the DC-8 pressure transducer temperature measuring thermistors was completed, and an extensive analysis spanning several years of data files of the DC-8 Rosemount pressure transducer calibrations was done, including a new digital transducer made by Druck.

In SONEX we had two INS units on the DC-8 separated by about 15 meters. By comparing their outputs we discovered flexures of a few tenths of a degree during both normal flight operations and our MMS maneuvers which are useful in correcting the AOA and yaw measurements.

For further details please refer to the final yearly reports **Tropospheric-Stratospheric Measurement Studies** for 1996-1997, 1997-1998 and 1998-1999

PROGRESS AND STATUS OF TROPOSPHERIC-STATOSPHERIC STUDIES

(1) General items

I attended the SONEX three day planning meeting at Goddard Space Flight Center in June 1997.

I went on the entire one month SONEX mission (18 flights, 112 hrs in the air) in early fall of 1997 which went from Ames to Bangor Maine to Shannon Ireland to Terceira Azores returning to Bangor and finally back to Ames. I flew most of the local flights and all of the transits. Aside from the data calibration and verification of data quality, a fairly extensive communication and interaction between the flight crew, other experimenters,(who were primarily atmospheric chemists) and the mission scientists was required during the mission to get a set of satisfactory MMS maneuvers. Note the presentation I gave regarding these maneuvers to the experimenters, the **MMS DC-8 Calibration Maneuvers SONEX** hand out given to the pilots, and the "Wiggle" curves as noted below.

Dr. E. Moore wrote a Matlab shell, adapting the FORTRAN MMS routines, that is a very good first cut to upgrading our whole calibration procedure and making up to date presentation quality graphs.

Two papers were written with coauthors, based on the SUCCESS flights. Both papers were peer reviewed, extensively revised and accepted for publication in GRL (see Publications).

(2)Reports and Memos

A presentation explaining to the DC-8 experimenters the necessity for the MMS maneuvers was given during the SONEX mission and is included as **MMS Maneu-**

vers, or *Why we suffer* .

A handout I produced for the pilots **MMS DC-8 Calibration Maneuvers SONEX** is included. We found out there is a training period to give us *good* MMS maneuvers within the limits of aircraft safety, passenger tolerance and mission flight time, but some pilots are better even the first time! This handout was made to start the discussion and explain just what we needed. I want commend the NASA pilots Jim Martin, Bill Brockett and Gary Tiffany, for their excellent ability to give us the good ones, holding the Mach, smooth wiggles, and avoiding Dutch rolls during the yaws! I want to especially thank Bill Brockett for his early great interest in the MMS wiggles, his experimentation in producing them, and his communication of all this to the other pilots.

During the planning sessions for SONEX with its requirements of flying in the very closely controlled track system over the North Atlantic, the question arose as to whether the MMS maneuvers would exceed the $\pm$ variations allowed in both altitude and left/right position. I therefore produced the "MMS Wiggle Curves" plots to answer these questions.

Calibration of the Rosemount DC-8 Pressure Transducers.—

An ongoing problem critical to the fundamental accuracy of the MMS data has been the laboratory calibration of the Rosemount pressure transducers. (see previous yearly reports, particularly 1997-1998, 1995-1996) We use these transducers in both the DC-8 and the ER-2 aircraft to measure the static, dynamic and total pressure.

There are two types of corrections required to give reliable pressure values. First is correction for position error i.e. the static pressure tap orifice location on the aircraft is not exactly at the right place for a particular Mach number or aircraft attitude. A good part of our MMS maneuvers is devoted to determining this error. The static tap corrections are typically a few tenths of a mb, with uncertainties of

10 %. Secondly *but of no less importance* is the basic transducer conversion of its input pressure into a certifiable output pressure value. It is this correction we are concerned with here.

Rosemount specifications generally give ± 0.1 % of full scale as the accuracy using a single linear coefficient without further calibration for the 1201F2A12 series. For a 32" Hg = 1083.26 mb, 5 volt transducer this amounts to ± 1 mb offset errors while the typical 2 mv of noise on the A/D converter will result in ± 0.43 mb noise. For a 5 psia = 344.74 mb, 5 volt transducer the corresponding offset error would be ± 0.34 mb and the noise would be ± 0.14 mb. These accuracies are claimed over the whole temperature operating range, typically -50 C to + 70 C. At 40 Kft = 12.192 km, at Mach = 0.70, $p = 187.539\ mb$, $q = 72.596\ mb$, $T = 216.650\ K$, $TAS = 206.4$ m s^{-1} A static pressure p error of 1 mb will result in an altitude error of 34 meters, and coupled with a dynamic pressure q error of 1 mb gives a Mach number error = 0.006, a TAS error = 1.76 m s^{-1} and a static temperature error = 0.36 K. The errors are proportional to the p and q errors, with the Mach error due to a q error being 2.6 times larger that of the p error.

For some time, we have had each of our transducers *individually* calibrated to assure proper operation as well as improving the error values. A typical calibration involves two separate runs taken on two separate days. Each run accumulates 40 to 50 voltage-pressure points gathered going either up-down-up or down-up-down over the 0 to 5 volt output range to eliminate possible hystereses effects. At this level of calibration a typical 3rd order polynomial fit

$$p_{mb} = A_0 + A_1 * V + A_2 * V^2 + A_3 * V^3$$

where p_{mb} is the calibration pressure and V is transducer voltage, yields a result (including both sets of data) that has a standard error of the estimate $\sigma \approx \pm 0.03$ mb or less. This overall fit error magnitude is principally driven by the uncertainty δA_0

of the A_0 term. Third order fits of these transducers are sufficient to give systematic deviations of the fit that are not distinguishable from those due to the irreducible random point to point and hysteresis errors.

While this improved accuracy is the good news, the bad news is that not only are the overall fits are now temperature dependent, with the individual coefficients A_i temperature dependent at their $\pm\delta A_i$ accuracy level. There is significant variation in the higher order coefficients relative to the room temperature values. We have had the transducers calibrated twice now, a year apart, in a temperature controlled enclosure over the expected or measured range of temperature in the aircraft.. From the polynomial calibration coefficients resulting at each temperature, I produce a low order fit to the A_i pressure ploynomial coefficients as a function of T , typically 1st or 2nd if enough temperature values warrant. [see attached sheets giving typical polynomial coefficients as a function of temperature and the 3d order plot of p(T,V) - p_{nom} for the 32" Hg P_{tot} transducer sn 1613].

A memo summarizing *room* temperature calibrations utilizing various standards for the four transducers used on the DC-8 over the last few years, is attached. This is a preliminary version of this work; it is still a work in progress. It is clear however that the primary calibrations need further attention.

Druck transducer.—

We have recently acquired a new completely digital temperature compensated transducer made by Druck, whose factory calibration sheet and my analysis is attached. The principal on which this instrument operates is that tension changes (produced from the applied pressure), change the resonant frequency of a micro etched silicon structure. The frequency is counted for a short ($\approx$ 0.4 sec) time and converted to pressure with accuracies of order 0.02 mb for a 1 atm range transducer. We have great hope for this transducer both as a laboratory standard to calibrate the analog Rosemount units, and for use in the ER-2 and DC-8.

Thermistor calibration.—

The temperature dependent pressure transducer calibrations were set up so as to include a temperature calibration of the thermistors enclosed in the three insulated and temperature controlled boxes containing both static units, the dynamic, and total pressure transducers. I set up a calibration fit program that read the voltage, temperature data, and computed the least squares fit of the form

$$T(C) = a_0 + a_1 * x + a_2 * x^2$$

The independent variable x is

$$x = \ln(\frac{R(t)}{R_{s\tan dard\_T}}) = \ln(\frac{R_0 * (Epvolt - V_{thermistor})}{R_{s\tan dard\_T} * V_{thermistor}})$$

where $V_{thermistor}$ is the thermistor, $Epvolt = 5\ V \ = V_{thermistor} + V_{bias}$ is the total voltage divider drop. Both the a_i and the resistance ratio $R_0/R_{s\tan dard\_T}$ were determined.

Unfortunately a wiring error not discovered until after the flight series was over gave us a backward, ie not V_{bias} as expected but $V_{thermistor}$ for all of the units. Because of this we were worried during the SONEX mission that the *Ptot* transducer in particular was overheating, so we disabled the *Ptot* Minco heater during the test flights, and later stripped some of the insulation off of the total pressure box. As it turned out the Minco heaters did a fair job of keeping the other transducers at a constant temperature.

The thermistors functioned OK but had not been individually calibrated. In particular we did not know the resistance ratio which is close to unity. The calibration fits agreed quite well with the manufacturer handbook thermistor table. The standard error of the estimate of the least square fits was ≤ 0.2 C. with only one being $\gtrsim 0.01$ C These final calibration results are attached.

(3) DC-8 air data corrections

Because of the greatly expanded operating envelope of the DC-8 compared to the ER-2, a much more complex form of the various air data corrections has been devised. Fluid dynamic similarity specifies that the corrections to flow related quantities can be functions of attitude (yaw, angle of attack), Reynolds number and Mach number. These changing flow conditions primarily affect the static tap corrections and the yaw and AOA corrections. In addition fuel burn off during flight changes the required lifting wing vortex strength which affects the upwash angle. The corrections were modeled with adjustable coefficients to be determined as functions of the similarity parameters. The constants were determined for each calibration maneuver. These "constants" were then least squares fit as a functions of the Mach, and attitude (AOA and yaw as indicated). The ensemble of calibration maneuvers over the whole SONEX flight series were planned to span the required range of the Mach number.

A new feature of the SONEX data was the inclusion of a second INU (LTN100G or EGI) in addition to the LTN 72RH on the DC-8. The comparison of the two INS outputs has shown that the DC-8 has enough structural bending (a few tenths of a degree in the 15 meters longitudinally between the two units) in normal operations as well as the MMS maneuvers to feed through into the vertical wind in particular. The flexures which will affect the yaw and AOA measurements are related to the attitude and body accelerations which we measure with the EGI.

During the SUCCESS mission we included a term in $-L\dot{\phi}/TAS$, where L is a fuselage radius lever arm (fit as a function of Mach and AOA) TAS is the true air-speed, and $\dot{\phi}$ is the rolling rate to both yaw and AOA measurements, which corrected apparent spikes in the wind values during the rolling events. During SONEX we realized that the 858 AOA probe on the right hand side of the DC-8 is mounted with a ≈ 5 degree upward tilt from the horizontal as viewed from the nose of the aircraft. This tilt was showing up as an erroneous feedthrough of the yawing motion into the apparent AOA angle even with no $\dot{\phi}$ term. The 858 yaw probe is properly mounted in the vertical direction symmetrically on the fuselage on top. We were able to eliminate this feedthrough by subtracting out about 10% of the yaw angle from the AOA angle. Surprisingly this non-orthogonal correction then eliminated entirely the need for the $-L\dot{\phi}/TAS$ correction. The magnitude of the $-L\dot{\phi}/TAS$ is of order 0.07 degrees for the DC-8.

MMS Maneuvers, or *Why we suffer*

S. W. Bowen, Paul Bui

Nov 2 1997

MMS output	certifiable accuracy	resolution		
P	$\pm 0.3\ mb$		$f < 2.5\ Hz$	$200 < p < 1000\ mb$
T	$\pm 0.3\ K$			$180 < T < 315\ K$
3-D wind (u, v, w)	$\pm 1m\ s^{-1}$	$\pm 0.05\ m\ s^{-1}$		
$\theta = T(\frac{p}{p_0})\kappa$				
$\varepsilon\ [u, v, w]_{BP}$	$\pm 10\%$	$[0.8 - 1.5]$ Hz	$1^{-8} - 8^{-2}$	

To achieve this certifiable precision of the insitu meteorological variables on the DC-8, even during level flight, but including turns and climbs, we use the principal;

- The wind must be invariant to the aircraft motion [velocity, heading or attitude{roll, pitch}, or yaw, AOA]

When this made so, the primary air data quantities $[P, Pt, T,$ yaw, AOA] and the INS inputs $[\dot{x}, \dot{y}, \dot{z}$,roll, pitch, heading] used in the wind calculation have certifiable accuracies.

The maneuvers are designed to produce a clearly discernible signal (above the "noise"$\equiv$ natural variability) due to the known aircraft motion into the yaw and AOA , and all of the quantities used to determine the wind. When all the correlations of the known aircraft motion and the wind have been minimized, what remains is the true value and variation.

We calibrate the P, T transducer output (including time delays) in the lab as functions of P,T, and frequency.

Our MMS aircraft calibrations combine

(1) Initial calibrations to verify our modeling of the air data corrections over a range of Mach number,

(2) Recalibrations to verify continuing satisfactory operation of our instrumentation.

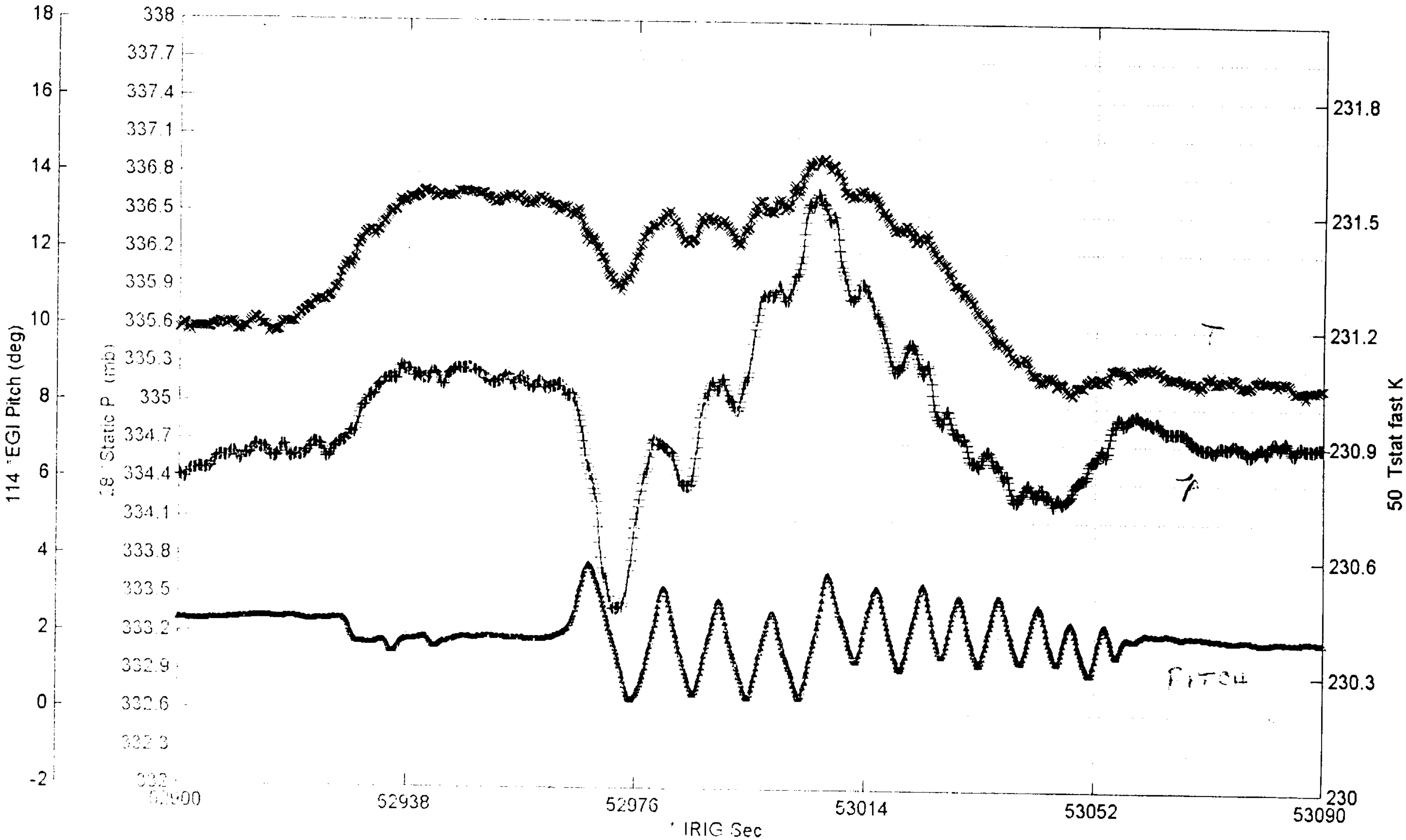
The MMS is a science instrument, not a facility.

V(?3) = .01

02-Nov-1997 15:07:09

D-971031.CV - 52800 to 53150
nominal (preliminary calibration)

Skip: 1
BUIANL



VM(3)= 0, AOA corrected to ?

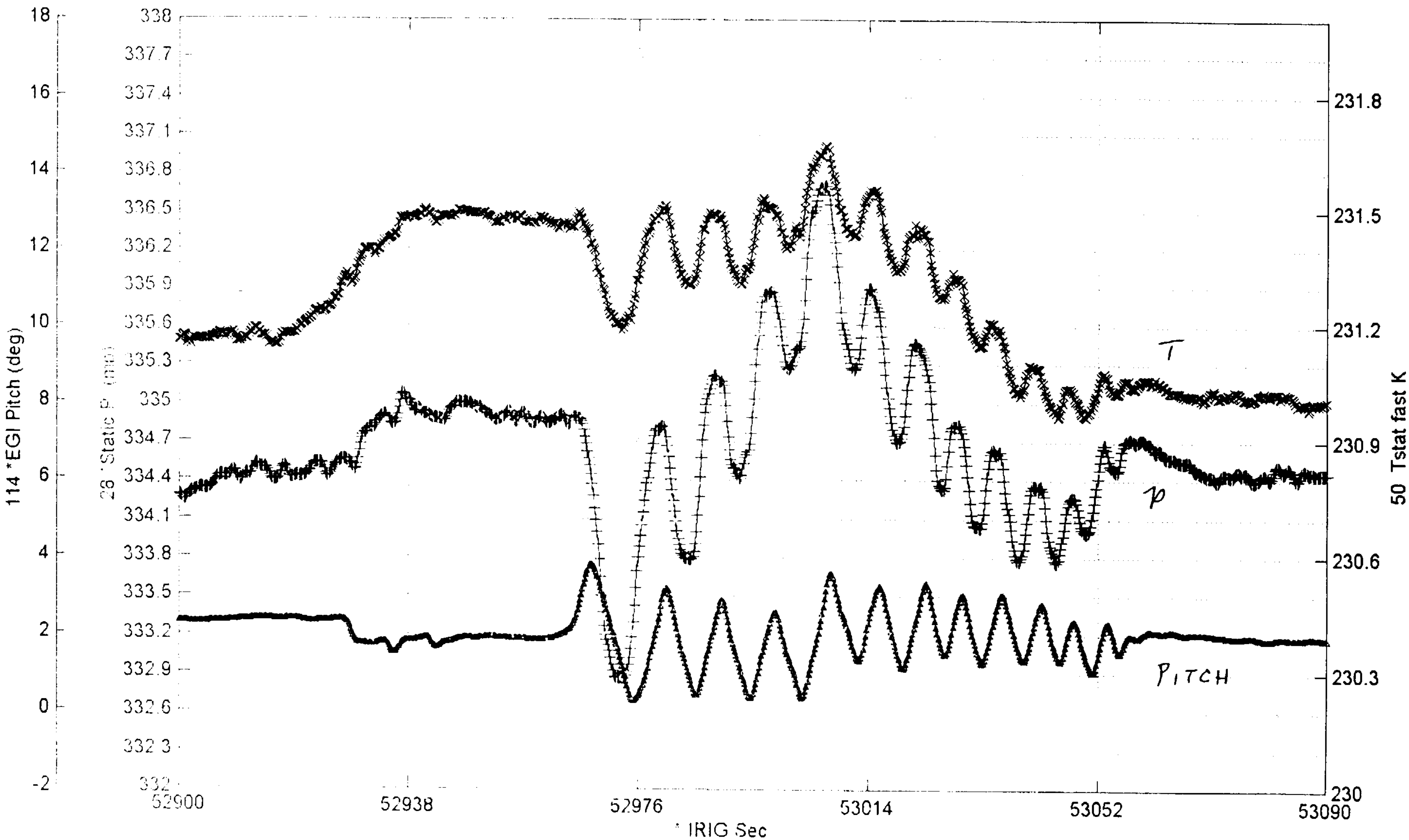
02-Nov-1997 15:01:13

D-971031.CV - 52800 to 53150

no static calibration to AOA

Skip: 1

BUIANL



1. MMS DC-8 Calibration Maneuvers SONEX

We will need at *some* time during *each* flight at one Mach to be decided;

(1) Pitching (wings level): 5 cycles, peak amplitude $\pm 0.2\ g$; 5 to 10 second period for each cycle. The DC-8 will ascend an descend about 10 to 30 feet during this pitching. Time required = 1 min.

(2) Yawing (wings level): 5 cycles, peak amplitude ± 2 deg; 5 to 10 second period for each cycle.

The wings should be kept reasonably level [$\pm$ 1 *to* 4°] during the yaws. Time required = 1 min. The Mach number *variation* should be kept within ± 0.02.

The pitch and sideslip maneuvers should be *sinusoidal* in nature, smoothly varying from the peak plus to peak minus.

(3) One square circle, either right or left, at approximately constant altitude consisting of;

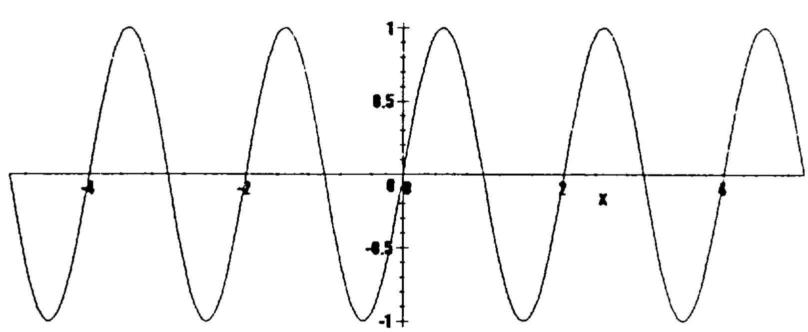
(a) Four 90 deg standard bank turns, connected by

(b) Four 20 second straight legs, wings level. The last leg heading will be the same as the original straight leg.

The square circle need not be done at either the same place or altitude as the wiggles (1),(2). The Mach number *variation* should be kept within ± 0.02.

The time required for the square circle = 8 min.

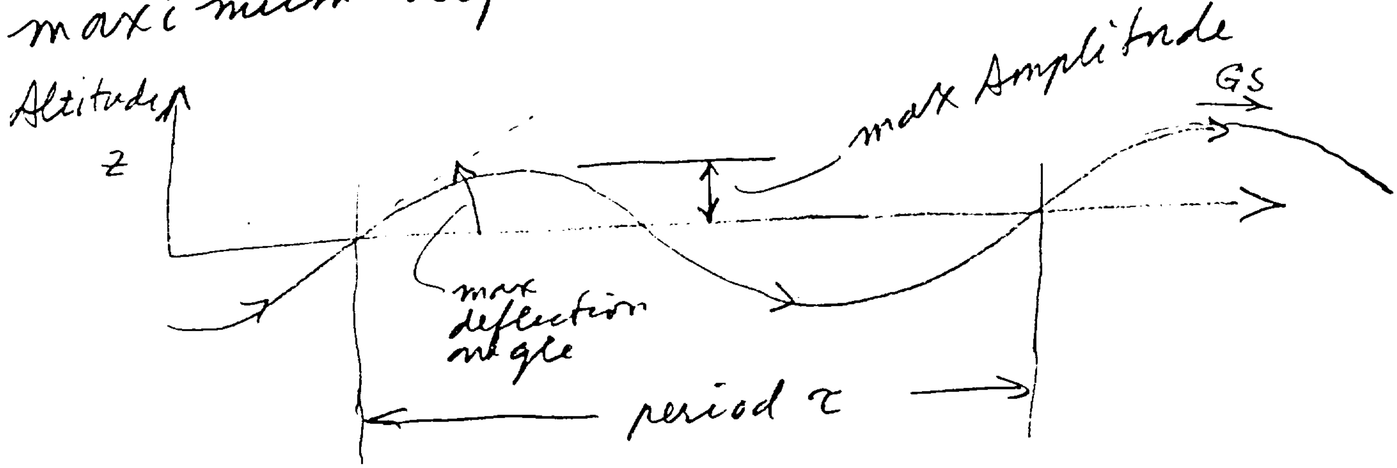
The square circle can be put in as two additional 90 deg + straight sections to a required 180 deg turn, or perform a keyhole turn rather than a simple 180 deg turn. We need a full 360 deg heading range for this maneuver.



Five Cycle Sinusoidal Plot. Peak amplitudes are $\pm$ 2 deg or 0.2 g
Peak to peak time intervals are 5 to 10 sec.

MMS Wiggle Curves

The following plots show (1) the maximum amplitude [±] in meters as a function of the whole period τ for various maximum g loadings and (2) the number of g's as a function of the period τ for various maximum deflection angles.

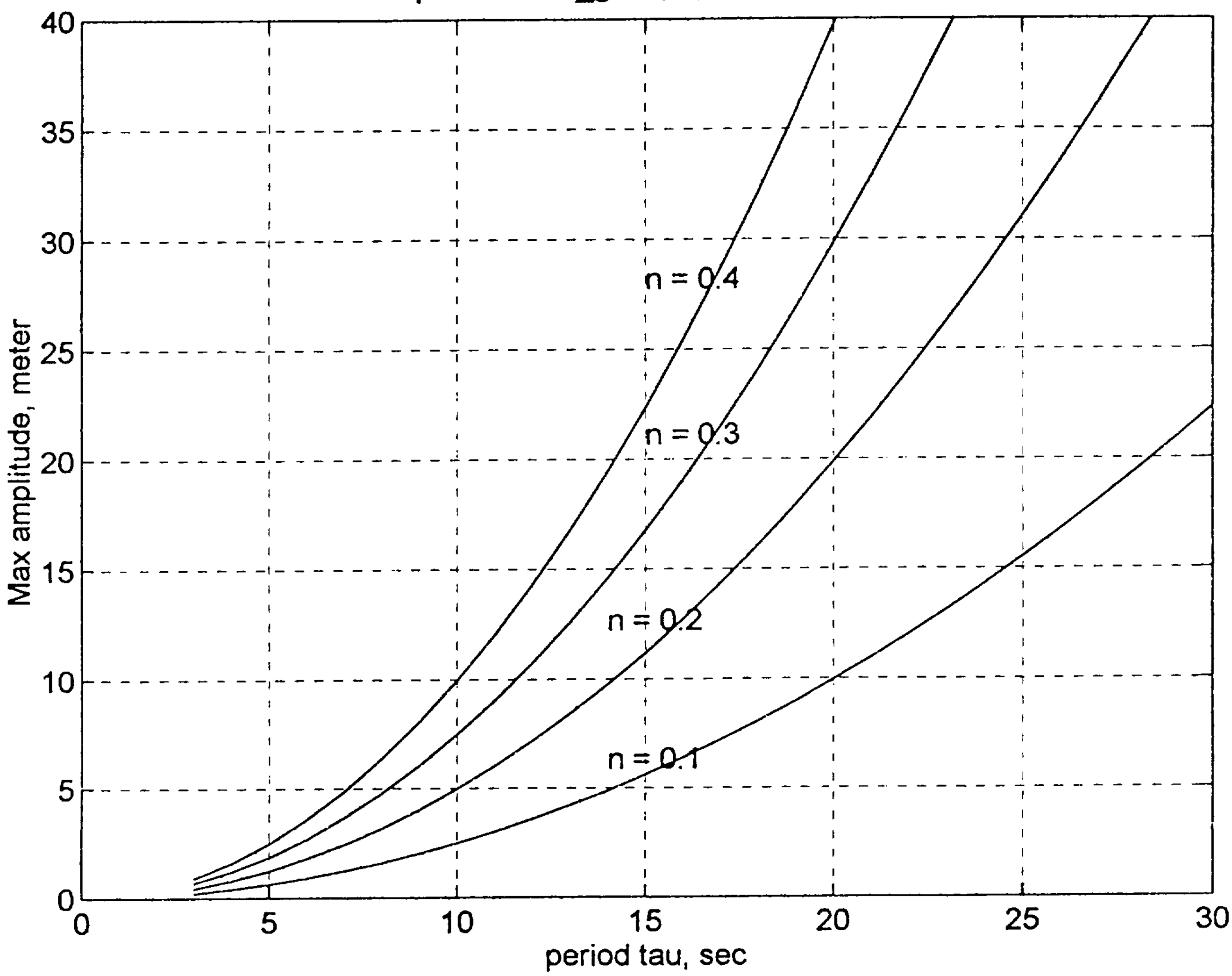


The assumed TAS = 242 m/s = 470 knot which is $\simeq$ .82 Mach above 36000 ft.

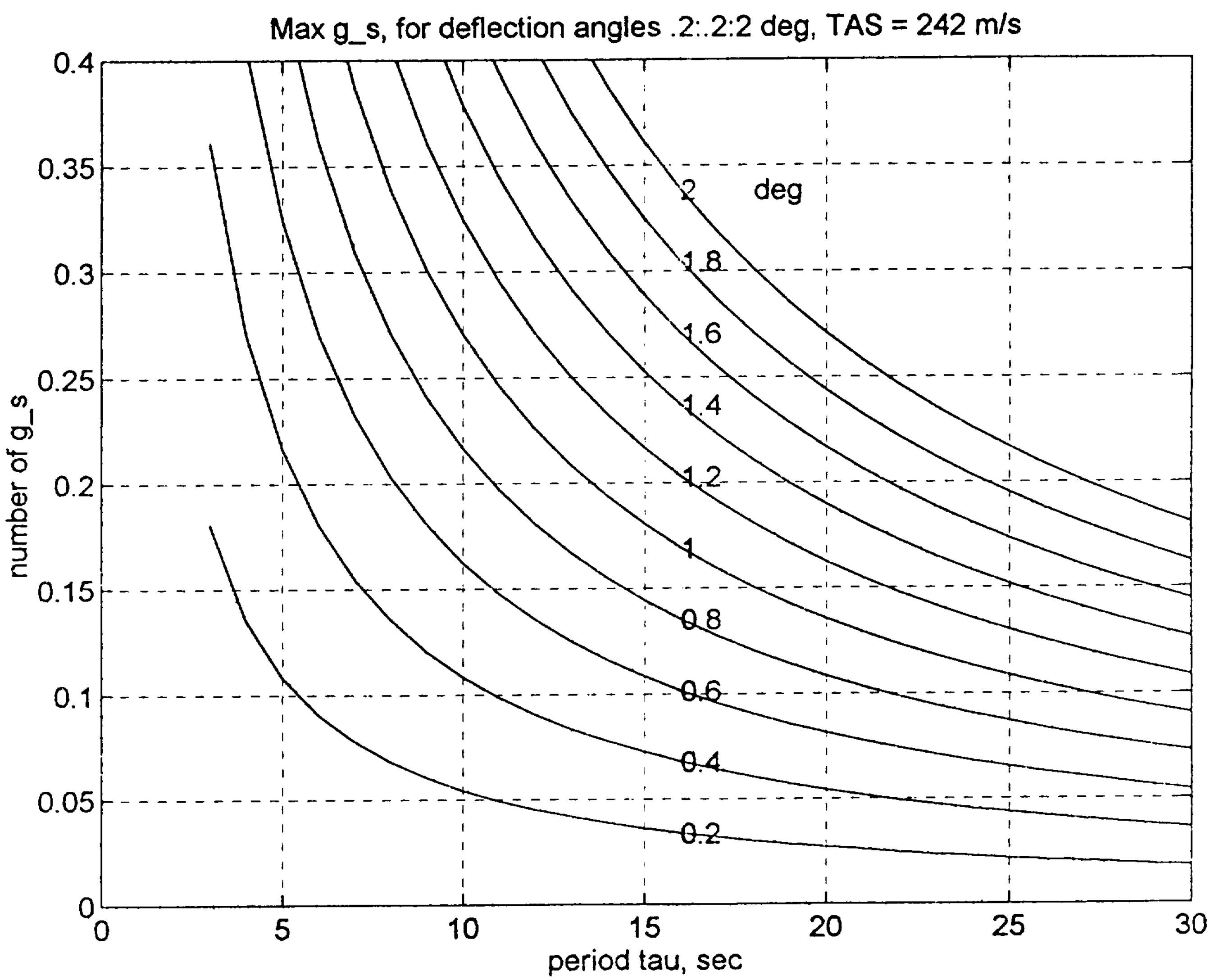
For example if $n = .36$ g's, $\tau = 15$ sec the max amplitude is ± 20.2 m = ± 66 ft above & below the level flight path and the maximum deflection angle is 2°. These curves work for both pitching and yawing.

SW Bowen
6/19/97

Max amplitude for n_gs .1,.2,.3,.4, TAS = 242 m/s



(1)


Max g_s, for deflection angles .2:.2:2 deg, TAS = 242 m/s
number of g_s
period tau, sec
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0
5
10
15
20
25
30
2 deg
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2

(2)

Part I
Physical or Compound Pendulum

The INS swing can be modeled as a physical pendulum, having a rigid arm, a lower mass consisting of the shelf and INU unit with the provision for adding upper weights on top to increase the period of swing.

Torque about pivot at P increasing θ is $= -(Mg\sin(\theta))d$
Angular momentum about pivot at P is $= I\dot{\theta}$
Thus

$$\frac{d}{dt}(I\dot{\theta}) = -Mgd\sin(\theta)$$

For small θ, $\sin\theta \approx \theta$. Let $\theta = \theta_0 e^{i\omega t}$

$$\begin{aligned} -I\omega^2\theta &= -Mgd\theta \\ \omega^2 &= \frac{Mgd}{I} \end{aligned}$$

The period $\tau = 2\pi/\omega$ is

$$\tau = 2\pi\sqrt{\frac{I}{Mgd}} \tag{0.1}$$

To find the cg, recall Σ *moments about* $G = 0$. The moment of the upper mass is $m_U * (x_U + d)$ with respect to G, and that of the lower mass is $m_L * (x_L - d)$ where d is the distance from P to G.

For the beam of length $L = x_U + x_L$ the mass of the beam from the cg at G to m_U is

$$M_U' = M_B\frac{x_U + d}{L}$$

and acts at the distance $(x_U + d)/2$ away from G, where M_B is the beam mass. For the section from G to m_L,

$$M_L' = M_B\frac{x_L - d}{L}$$

and acts at the distance $(x_L - d)/2$ from G.

Thus

$$m_U * (x_U + d) + M_U' * (x_U + d)/2 = m_L * (x_L - d) + M_L' * (x_L - d)/2$$

Solving for d = distance from the pivot to the cg, and using $\mu_U = m_U/M_B$, $\mu_L = m_L/M_B$, we find

$$d = \frac{(x_L^2 - x_U^2)/(2L) + x_L\mu_L - x_U\mu_U}{1 + \mu_U + \mu_L} \tag{0.2}$$

To find the moment of inertia I about the pivot P, we note that the moment of inertia of a rod having mass M and length L, about one end is

$$I = \int_0^L x^2 dm = M * L^2/3$$

where $dm = M * dx/L$.
For the beam and masses then

$$I = m_U x_U^2 + m_L x_L^2 + M_U x_U^2/3 + M_L x_L^2/3$$

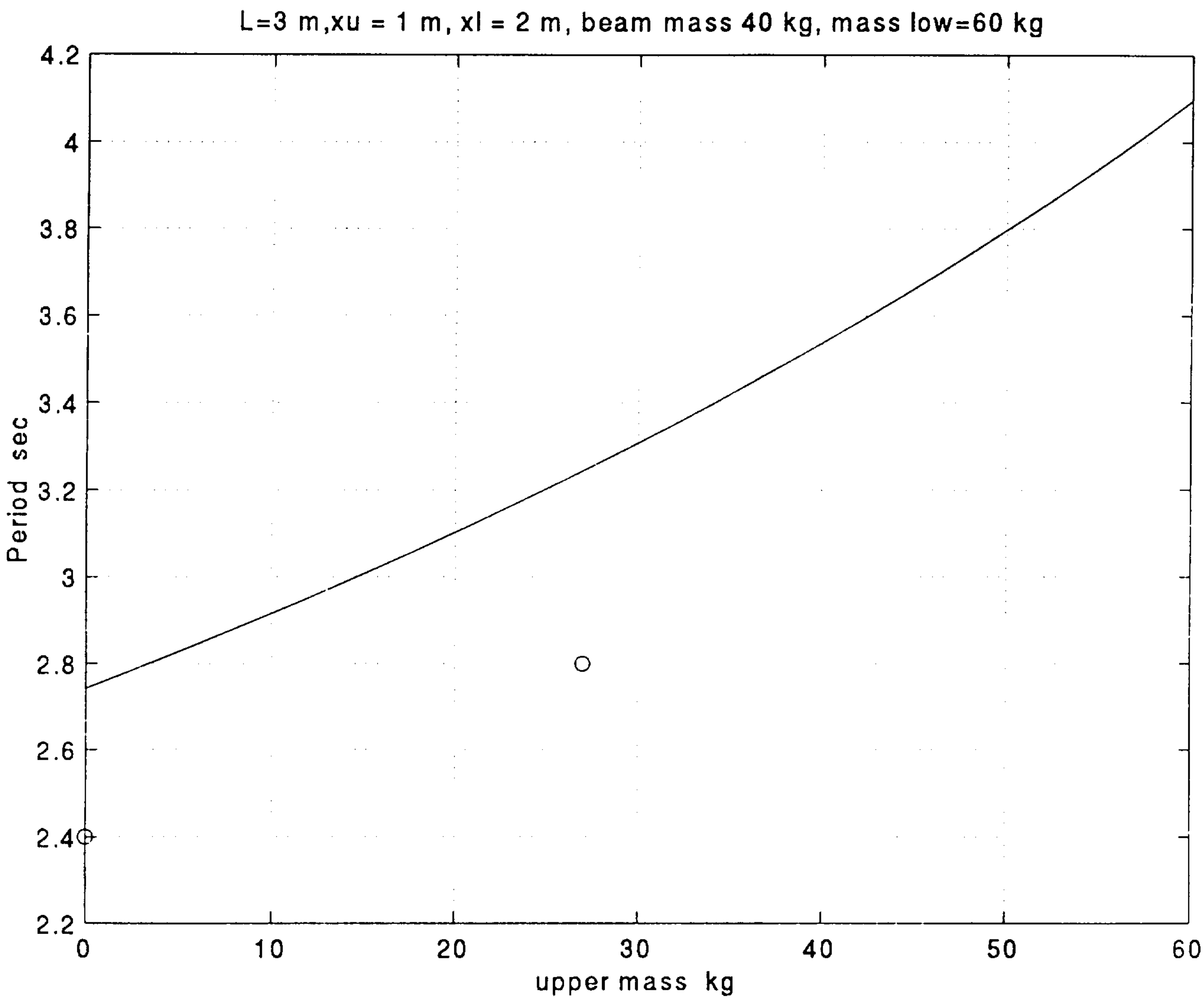
where $M_U = M_B x_U/L$, $M_L = M_B x_L/L$ and the total mass is

$$\begin{aligned} M &= M_B + m_U + m_L \\ &= M_B(1 + \mu_U + \mu_L) \end{aligned} \tag{0.3}$$

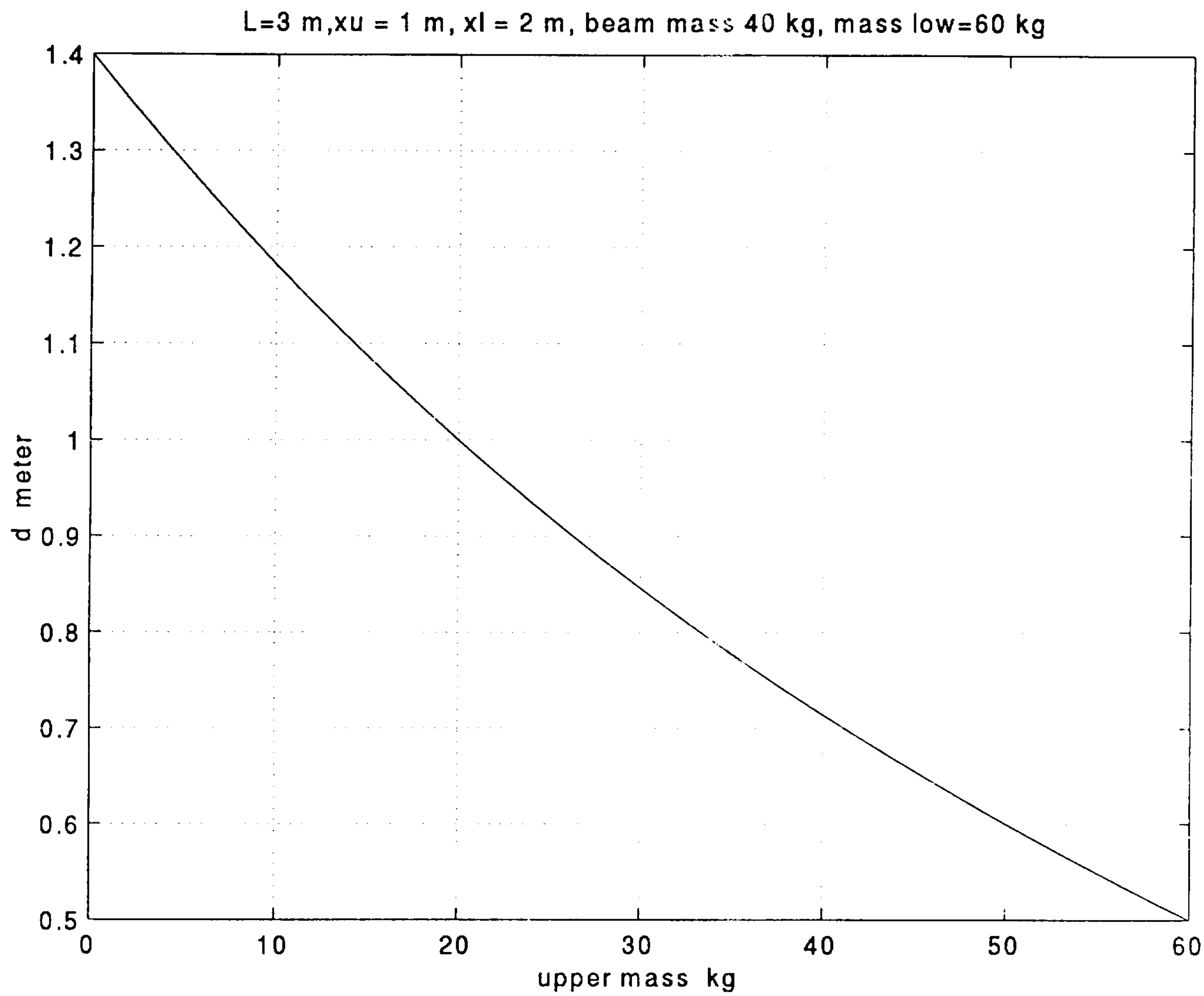
Thus

$$I = M_B[\mu_U x_U^2 + \mu_L x_L^2 + (x_U^3 + x_L^3)/(3L)] \tag{0.4}$$

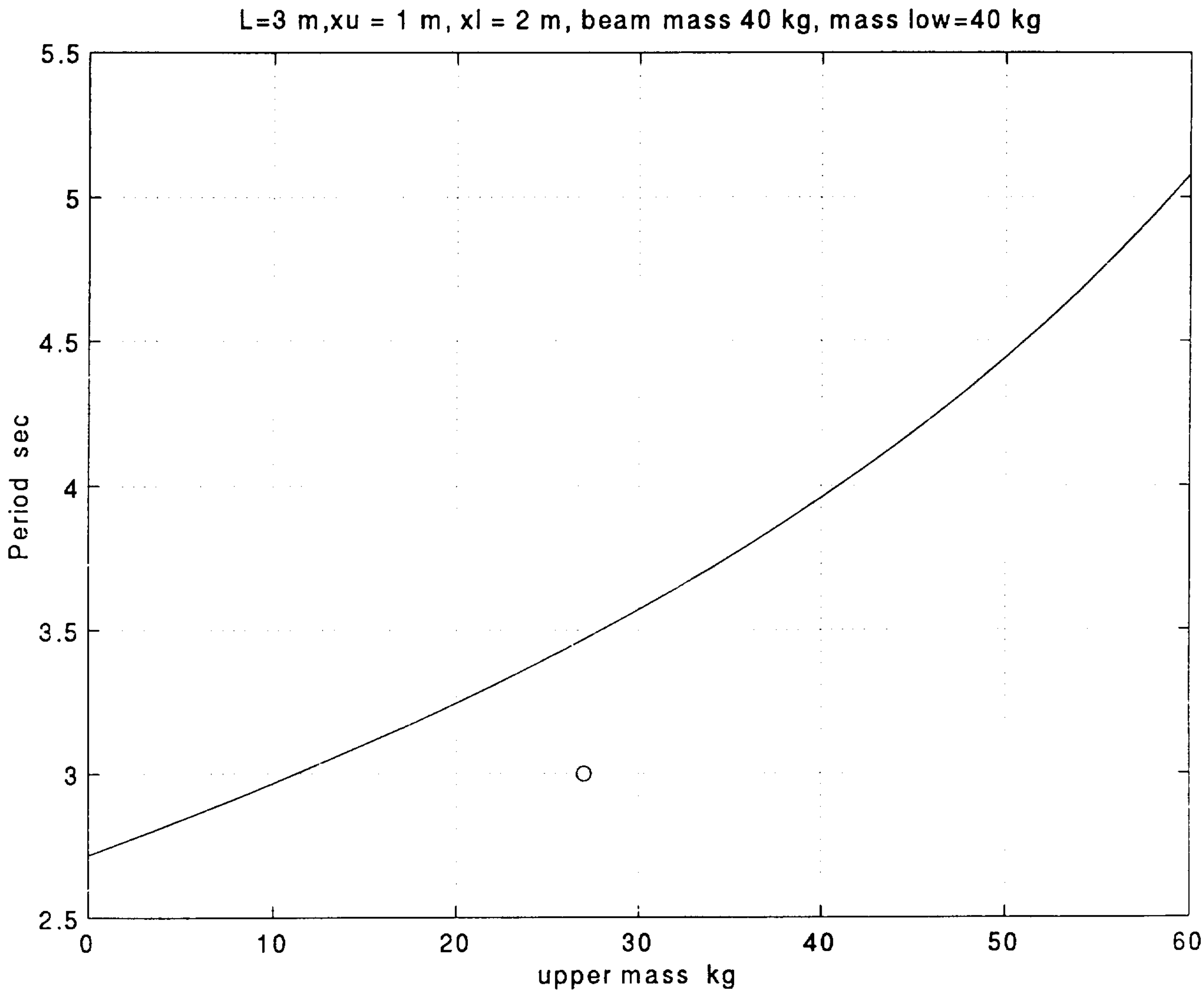
```
% physpen
% physical or compound pendulum

        %   emu<-------->P<--d-->G<----->eml
        %      <---xu---> <----xl------->
        %   beam mass =MB, upper mass =emu, lower mass =eml
        %   P= pivot, G= cg, M=MB+emu+eml, d= distance pivot to cg
        %   I = moment of inertia about pivot,
          %   xu = emu to P, xl= P to eml, L=xu+xl = beam length
          clear
          act0=[0 2.4;27 2.8]; % upper mass, period sec with EGI+LTN72

        %act1=[27 3.0]; % upper mass, period EGI only
        g=9.8;
        L=2.44;xu=.66;xl=1.78;  % dimensions
        emu=0:2:40; % upper weights kg
        %eml=15+10+25.5;sml=num2str(eml); % tray+EGI+(LTN72=25.5 kg)
        eml=15+10; sml=num2str(eml); % tray+EGI(10 kg)
        MB=21.5;sMB=num2str(MB); %  beam alone+hardware
        M=MB+emu+eml; % total mass
        muu=emu./MB;mul=eml/MB;
        d=((xl^2-xu^2)/(2*L)+xl*mul-muu*xu)./(1+muu+mul);
        I=MB*(muu*xu^2+mul*xl^2 + (xu^3 + xl^3)/(3*L));
        tau=2*pi*sqrt(1./(g*d.*M));
        figure(1);
        plot(emu,tau)
        hold
        plot(act0(1,1),act0(1,2),'ro')  % EGI+LTN72 data
        plot(act0(2,1),act0(2,2),'ro')   % EGI+LTN72
        %plot(act1(1,1),act1(1,2),'ro')  % only EGI
        grid
        xlabel('upper mass  kg')
        ylabel('Period  sec')
        title(['L=2.44 m,xu = .66 m, xl = 1.78 m, beam mass ',...
             sMB,' kg, mass low=',sml,' kg'])
        pause
        hold off
        figure(2);
        plot(emu,d)
        grid
        xlabel('upper mass  kg')
        ylabel('d  meter')
        title(['L=2.44 m,xu = .66 m, xl = 1.78 m, beam mass ',...
             sMB,' kg, mass low=',sml,' kg'])
```



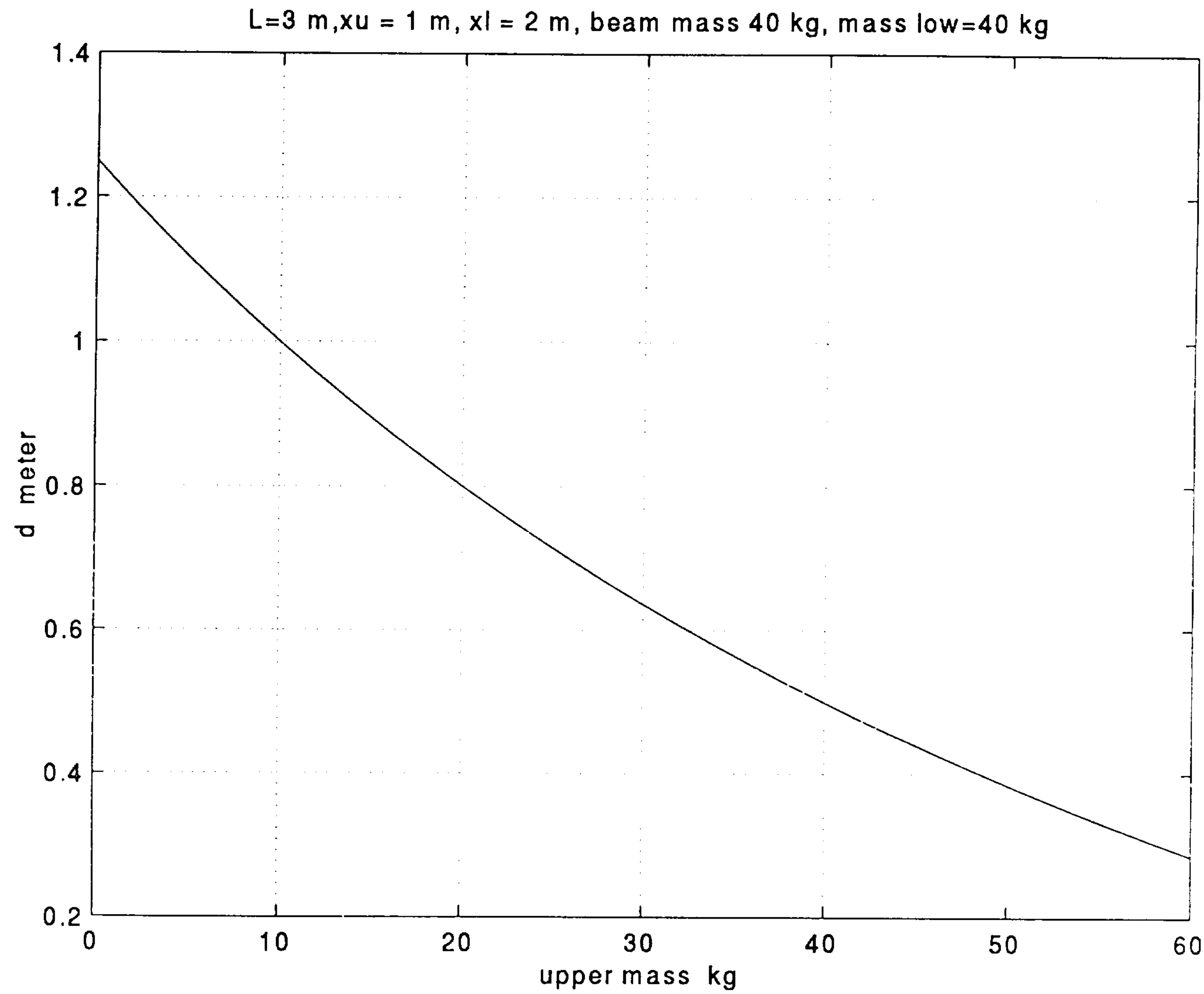
O = EGI + LTN72 DIFFERENCE DUE TO ESTIMATION OF PENDULUM BEAM MASS



L=3 m,xu = 1 m, xl = 2 m, beam mass 40 kg, mass low=60 kg
d meter
upper mass kg
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0
10
20
30
40
50
60


L=3 m,xu = 1 m, xl = 2 m, beam mass 40 kg, mass low=40 kg
Period sec
upper mass kg
5.5
5
4.5
4
3.5
3
2.5
0
10
20
30
40
50
60

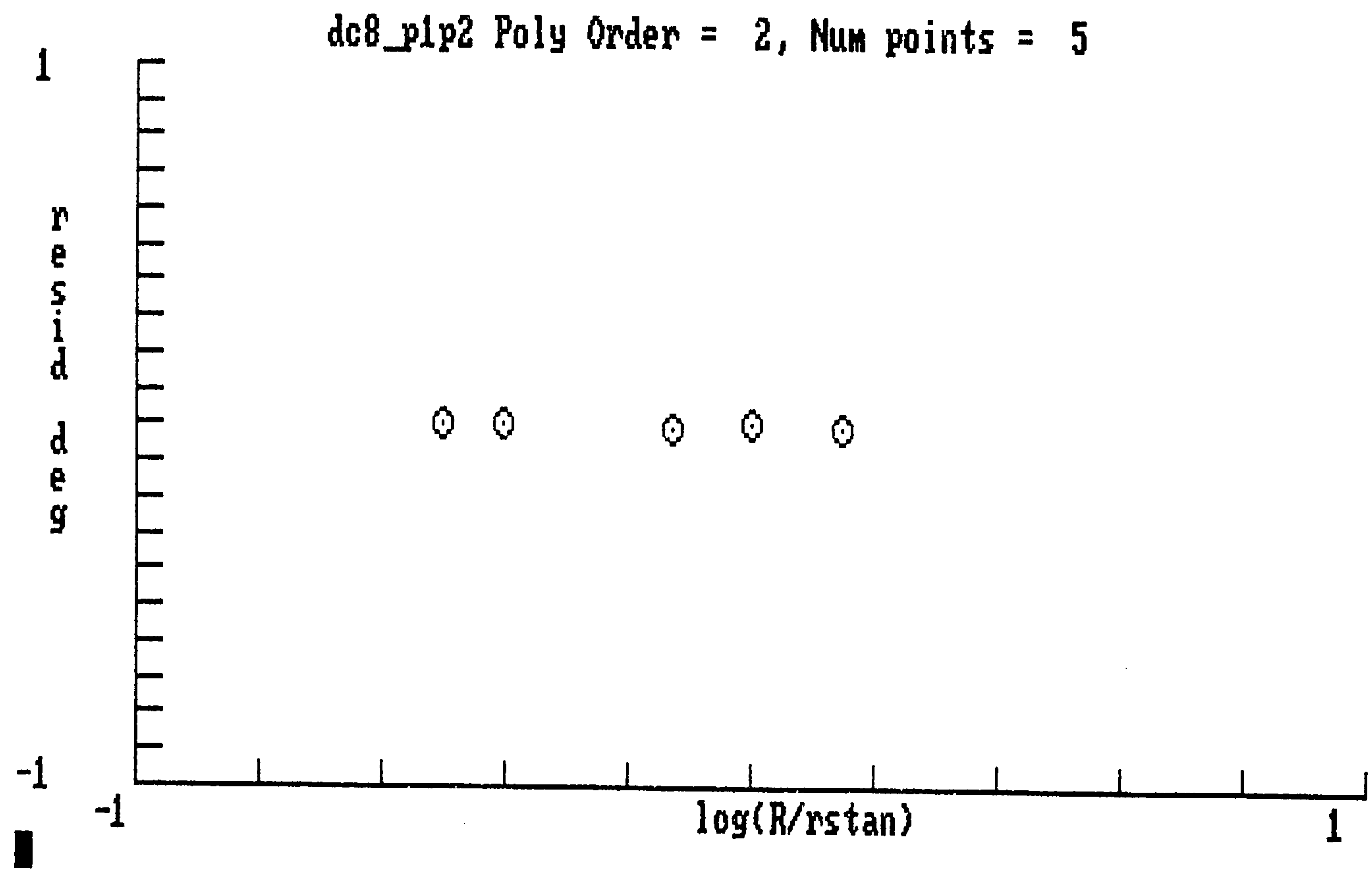
O = EGI ONLY



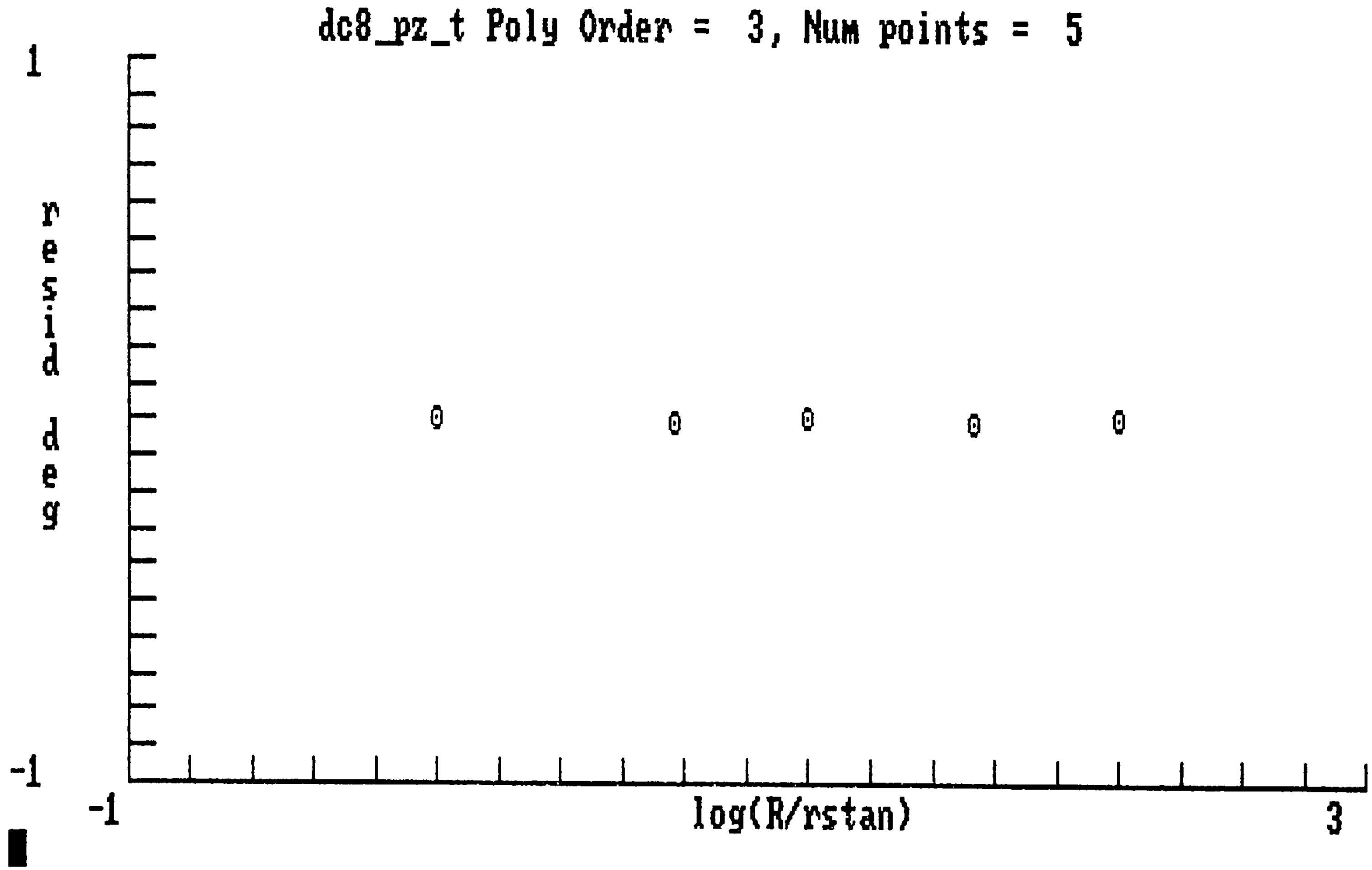
L=3 m,xu = 1 m, xl = 2 m, beam mass 40 kg, mass low=40 kg
1.4
1.2
1
0.8
0.6
0.4
0.2
d meter
0
10
20
30
40
50
60
upper mass kg

THERMISTOR CALIBRATIONS FOR SONEX PRESSURE TRANSDUCERS

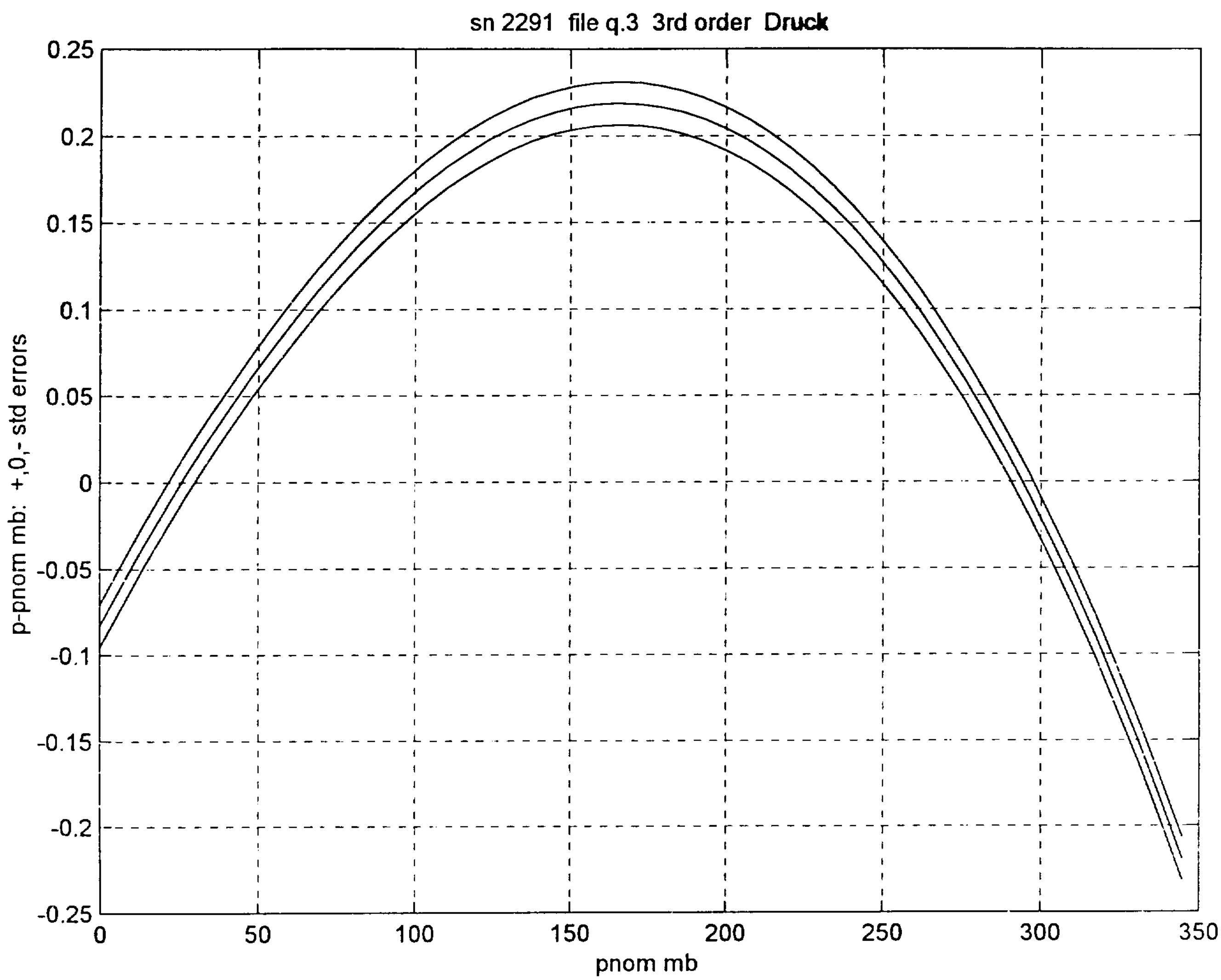
MARCH 1998

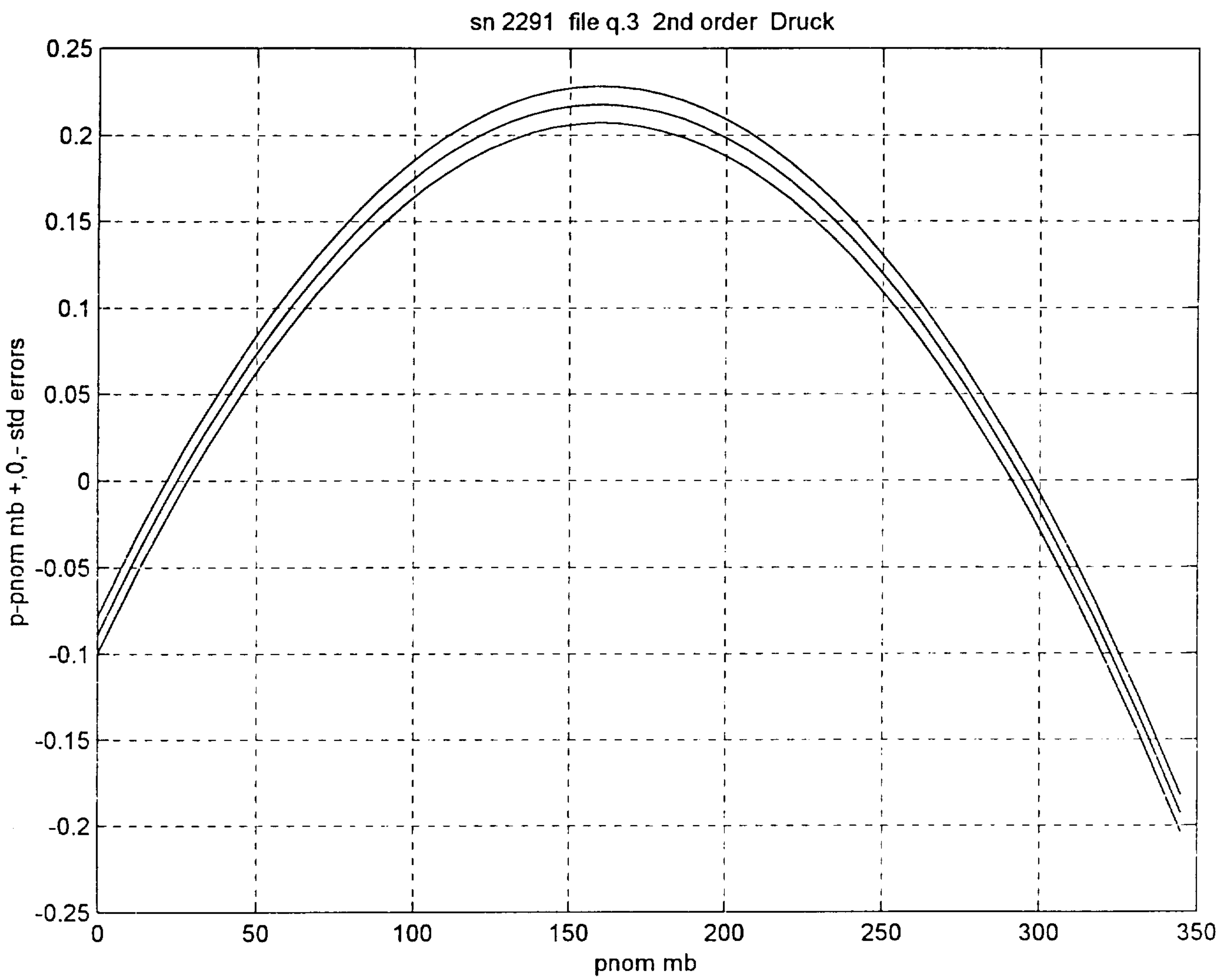

dc8_p1p2 Poly Order = 2, Num points = 5
1
resid deg
-1
-1
log(R/rstan)
1

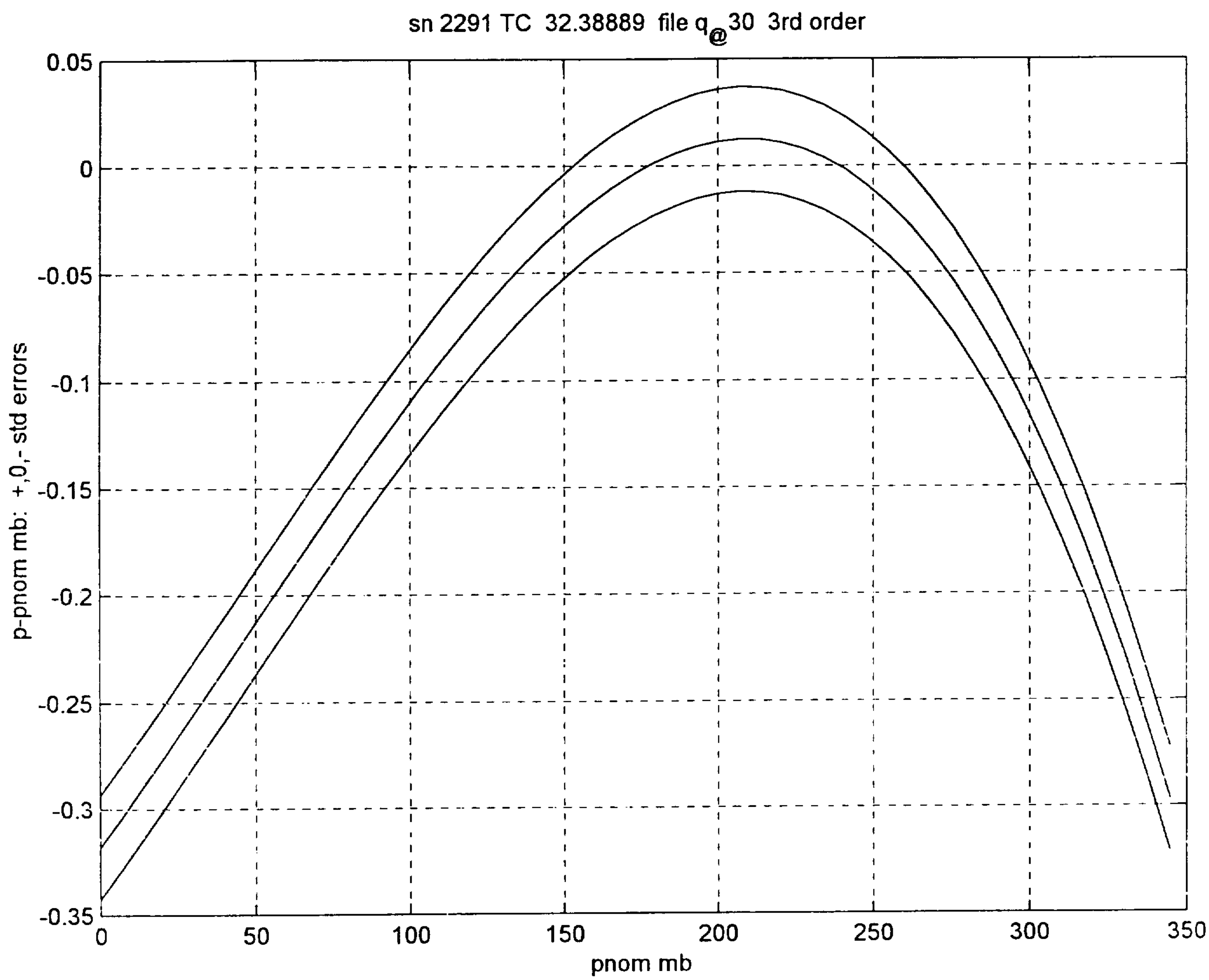
```
          Standard error of estimate =  7.101018871201386D-03
          Poly order =  2      Number of points =  5

        Y = SUM (A(J)*X^J) ; J = 0 TO  2   Num points  5

          A( 0 ) =  25.74315988694702  +/-  4.361343709575474D-03
          A( 1 ) = -27.52982616251586  +/-  3.230050769658745D-02
          A( 2 ) = -2.355885958562695  +/-  7.858226017426256D-02

         RESIDUAL RMS Y =  4.491266027821047D-03   C
           MAX RESIDUAL(meas-fit) =  7.617950439453125D-03
             AT  X = -4.369334755116583D-17
          R0/Rtstand =  1.133943534357378
           t Tstand =  25.75077819824219  deg C
          Ep =  5.126705  volts

     TITLE LINE :
THERMISTER CALIBRATION DC-8 P1&P2 PRESS SENSOR  TEL File=DC8_P1_P2
          FILE: dc8_p1p2
 auto file save name will be  sbdc8_p1p2
 name OK to save ? y/n  ?
```

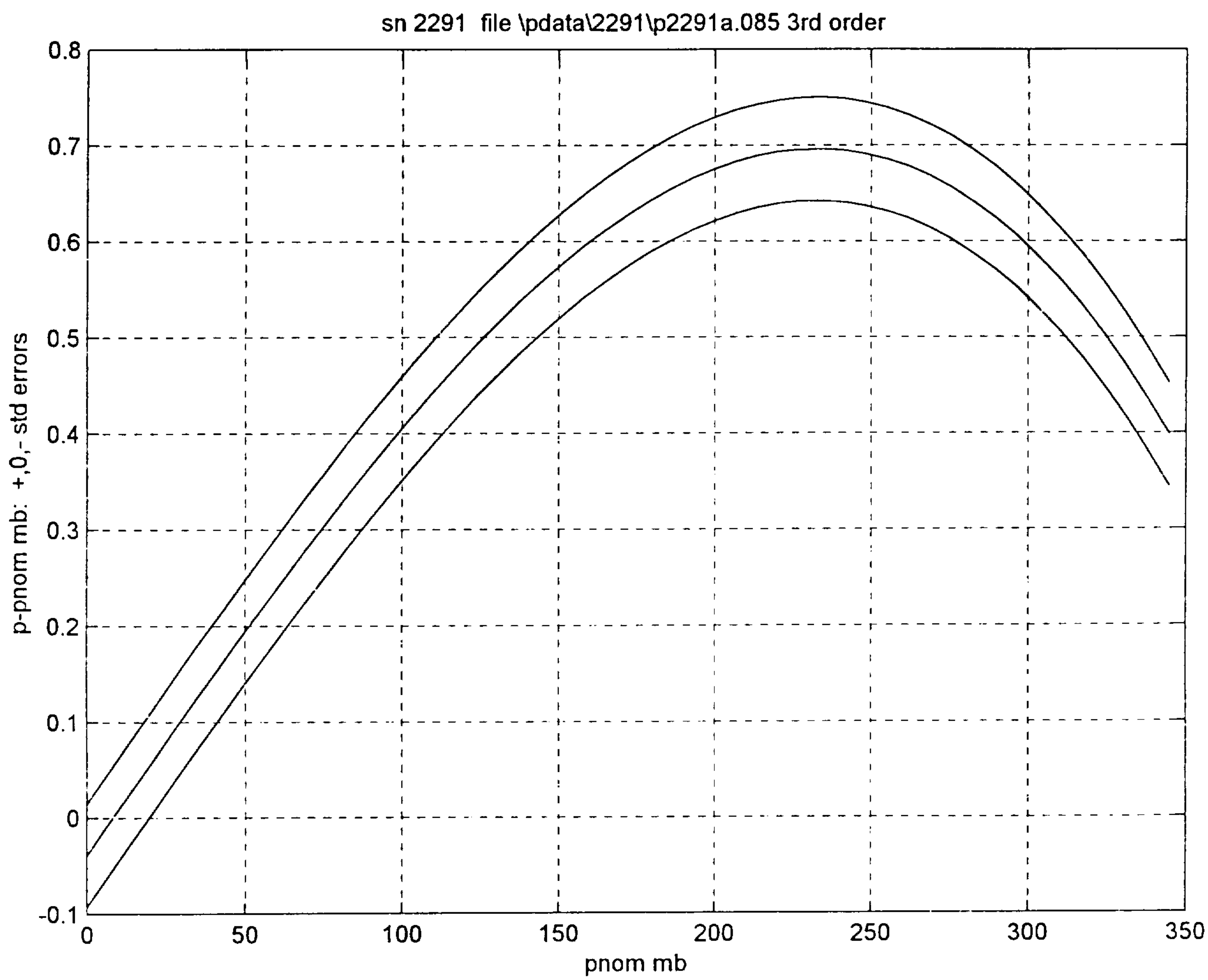

dc8_pz_t Poly Order = 3, Num points = 5
1
resid deg
-1
-1
log(R/rstan)
3

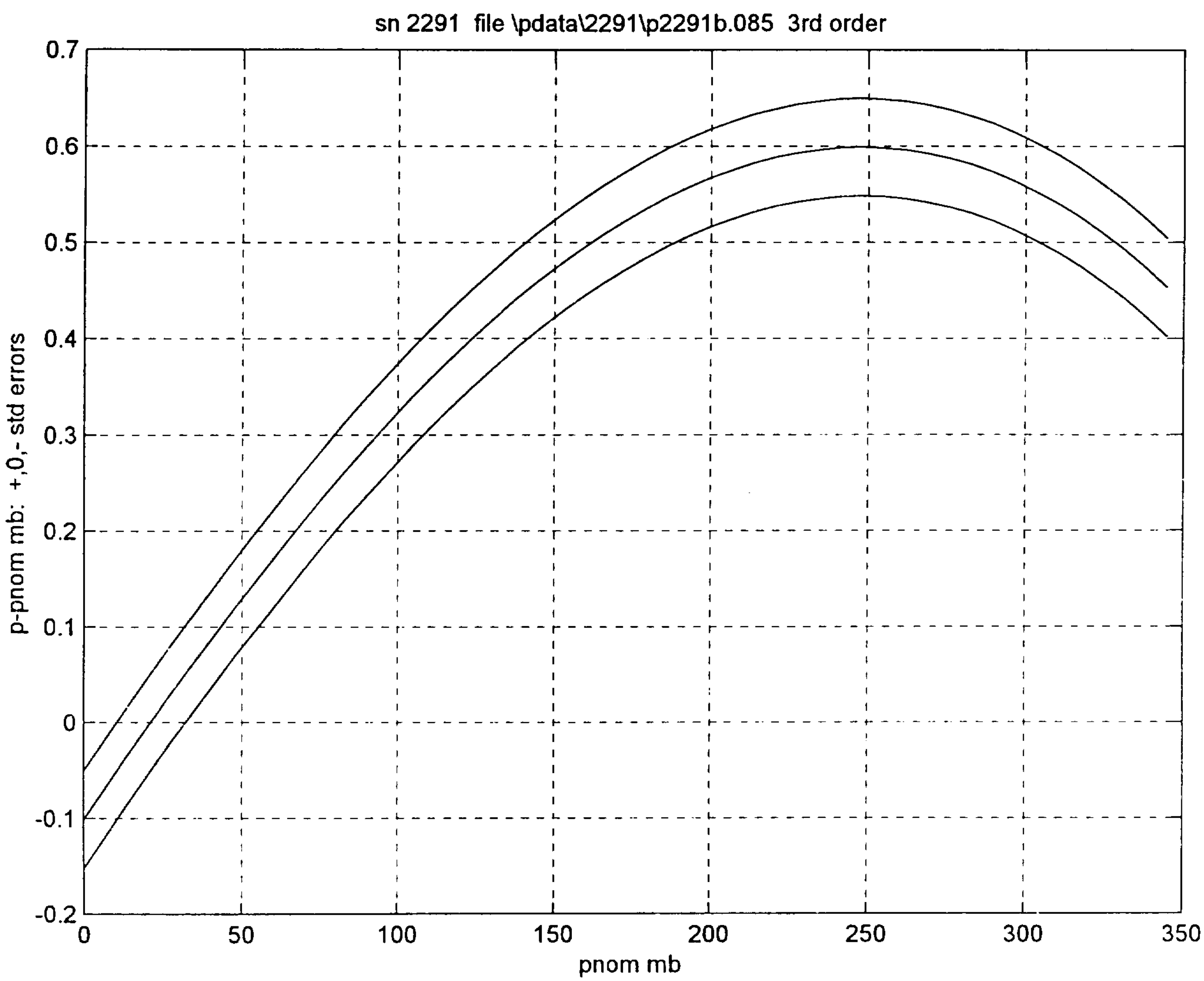
```
figure(7)
clear A
A=A7(:,1);siga=flipud(A7(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title('sn 2291  file \pdata\2291\2291a.106  3rd order ')
grid
pause

figure(8)
clear A
A=A8(:,1);siga=flipud(A8(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title('sn 2291  file \pdata\2291\2291b.106   3rd order  ')
grid
pause

figure(9)
clear A
A=A9(:,1);siga=flipud(A9(:,2));
p0=polyval(A,v);  % nom
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title('sn 2291  file \pdata\2291\2291t.106   3rd order  ')
grid
```

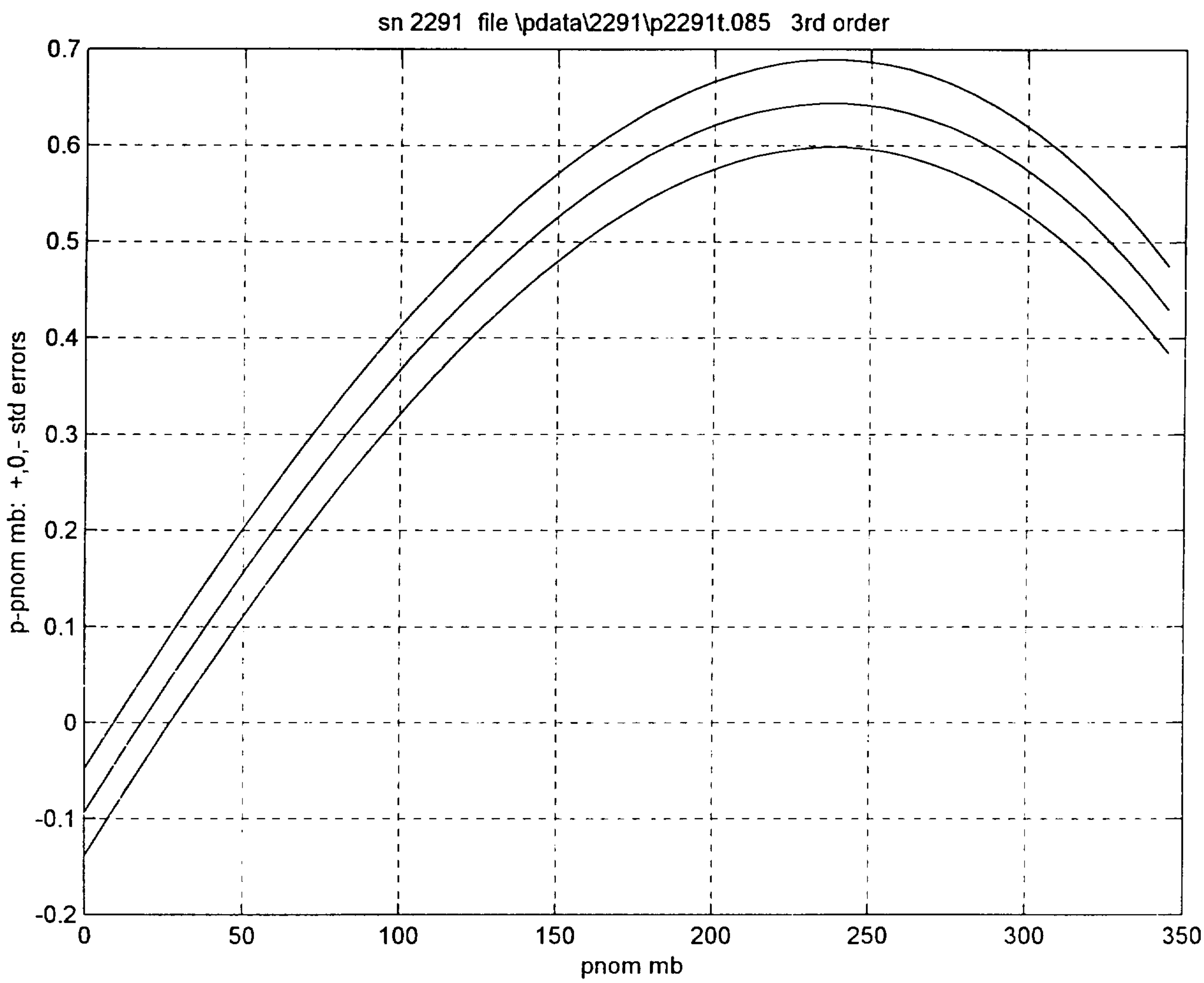

sn 2291 file q.3 3rd order Druck
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
p-pnom mb: +,0,- std errors
0
50
100
150
200
250
300
350
pnom mb

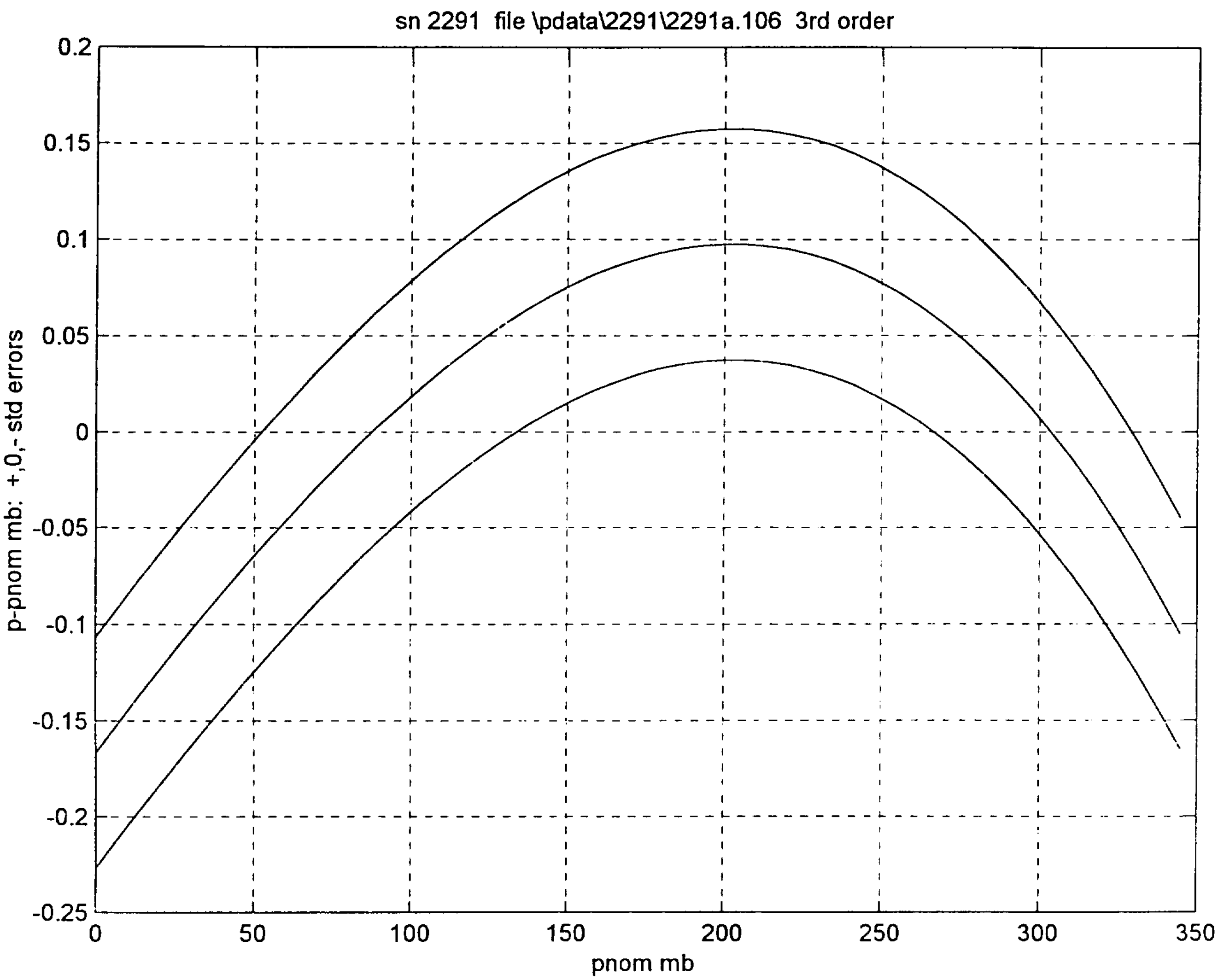

sn 2291 file q.3 2nd order Druck
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
p-pnom mb +,0,- std errors
0
50
100
150
200
250
300
350
pnom mb


sn 2291 TC 32.38889 file q@30 3rd order
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
p-pnom mb: +,0,- std errors
0
50
100
150
200
250
300
350
pnom mb

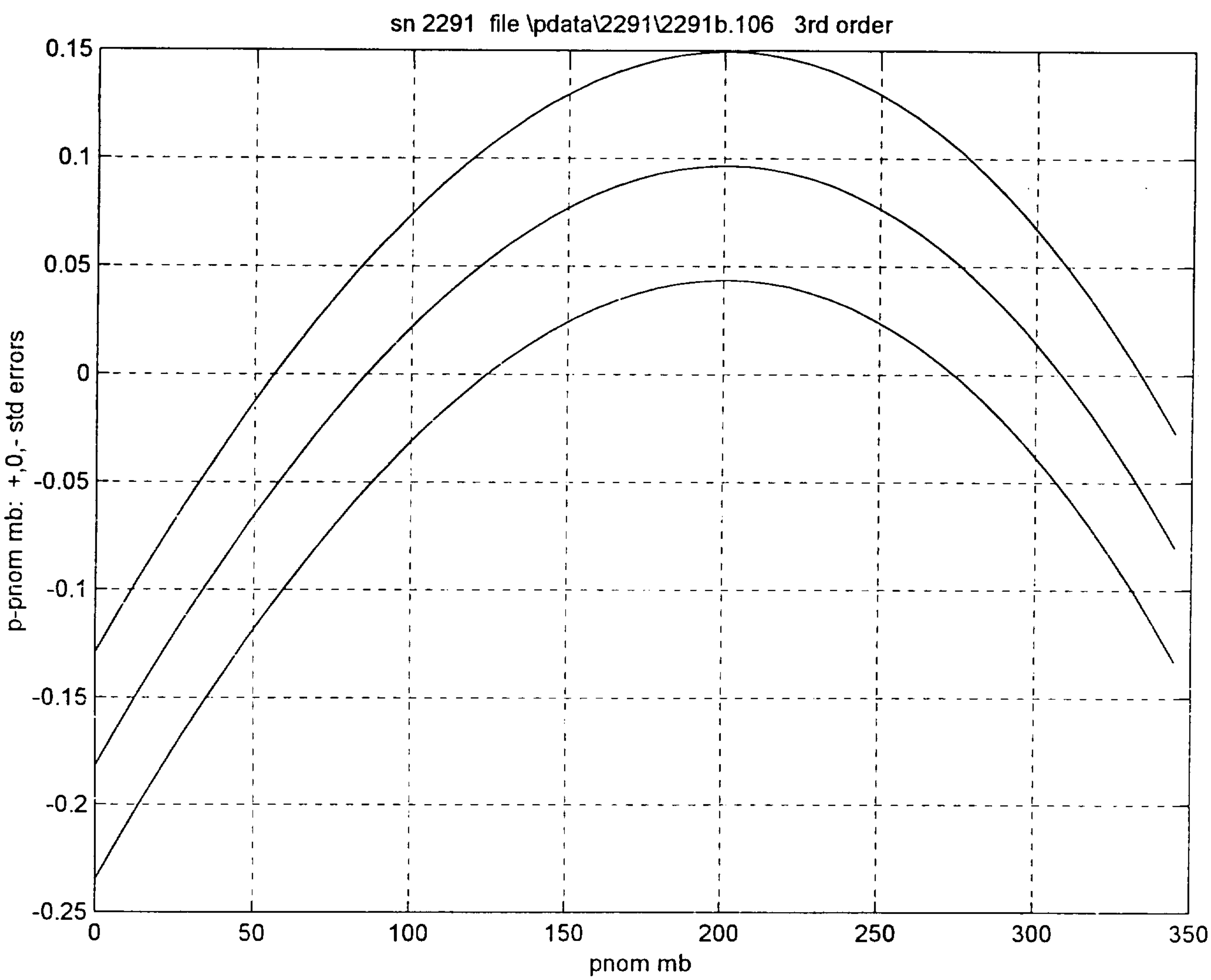

sn 2291 file \pdata\2291\p2291a.085 3rd order
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
p-pnom mb: +,0,- std errors
0
50
100
150
200
250
300
350
pnom mb

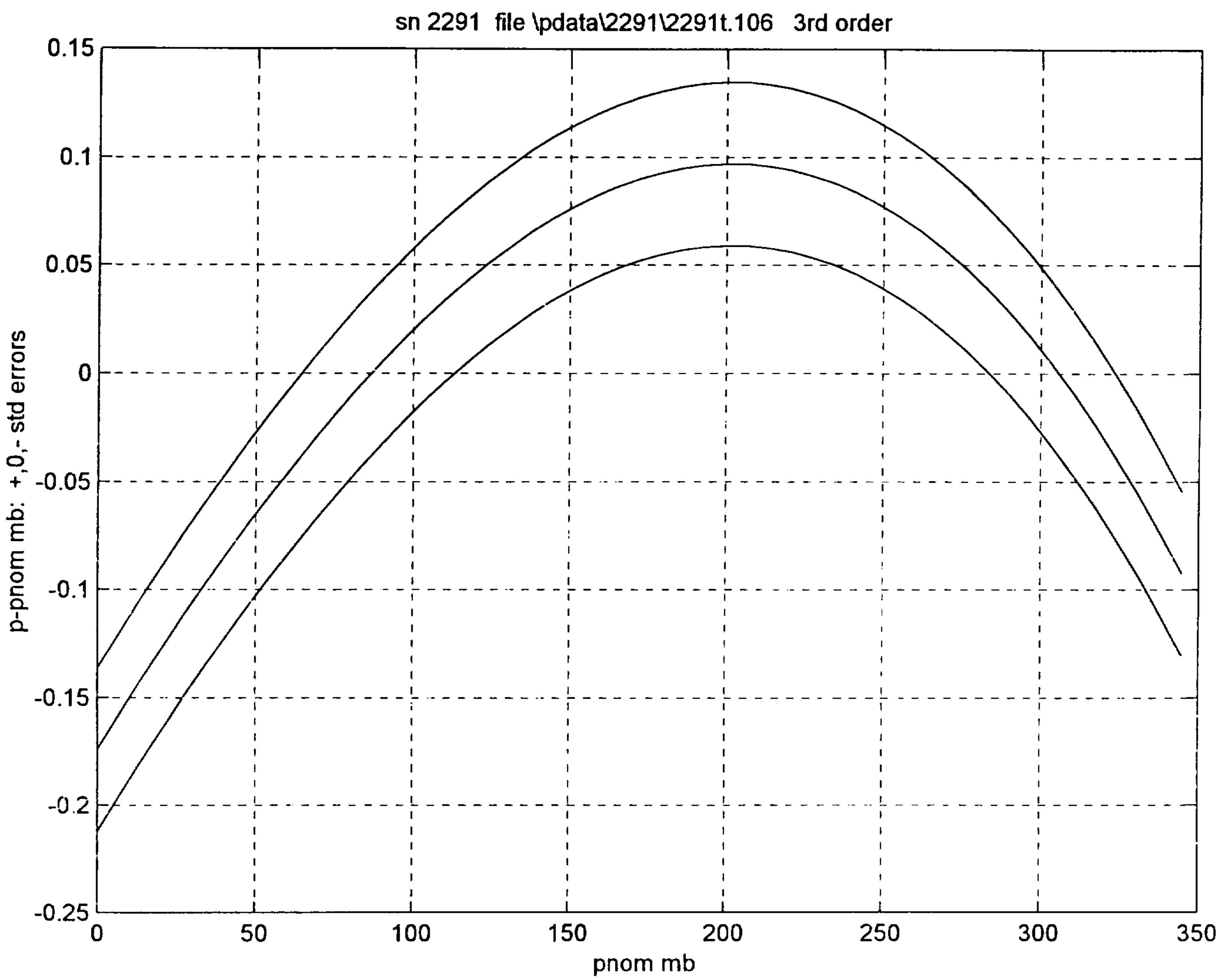

sn 2291 file \pdata\2291\p2291b.085 3rd order
p-pnom mb: +,0,- std errors
pnom mb
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
50
100
150
200
250
300
350


sn 2291 file \pdata\2291\p2291t.085 3rd order
p-pnom mb: +,0,- std errors
pnom mb
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0
50
100
150
200
250
300
350



sn 2291 file \pdata\2291\2291a.106 3rd order
p-pnom mb: +,0,- std errors
pnom mb
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
50
100
150
200
250
300
350


sn 2291 file \pdata\2291\2291b.106 3rd order
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
50
100
150
200
250
300
350
pnom mb
p-pnom mb: +,0,- std errors

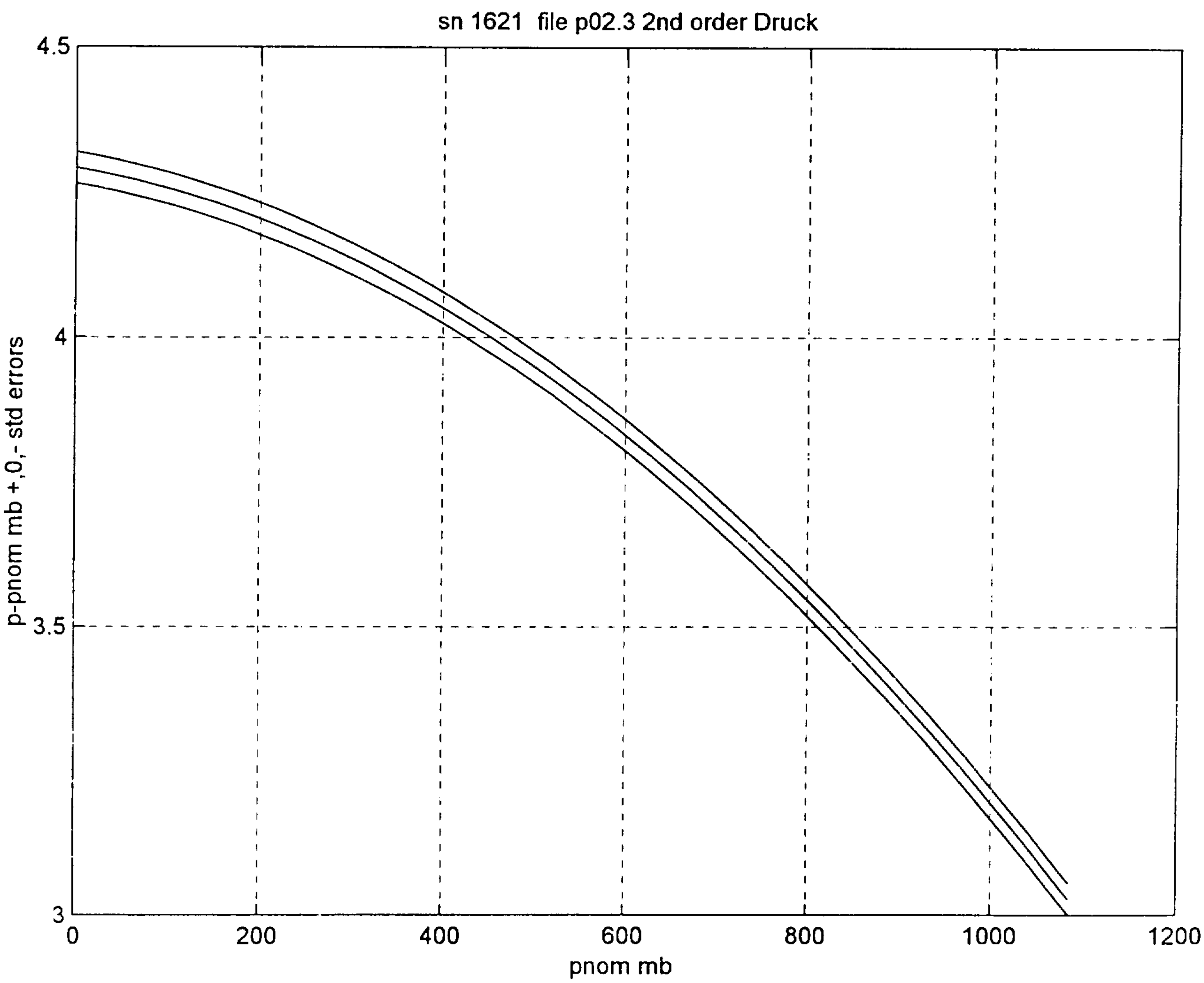

sn 2291 file \pdata\2291\2291t.106 3rd order
p-pnom mb: +,0,- std errors
pnom mb
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
50
100
150
200
250
300
350

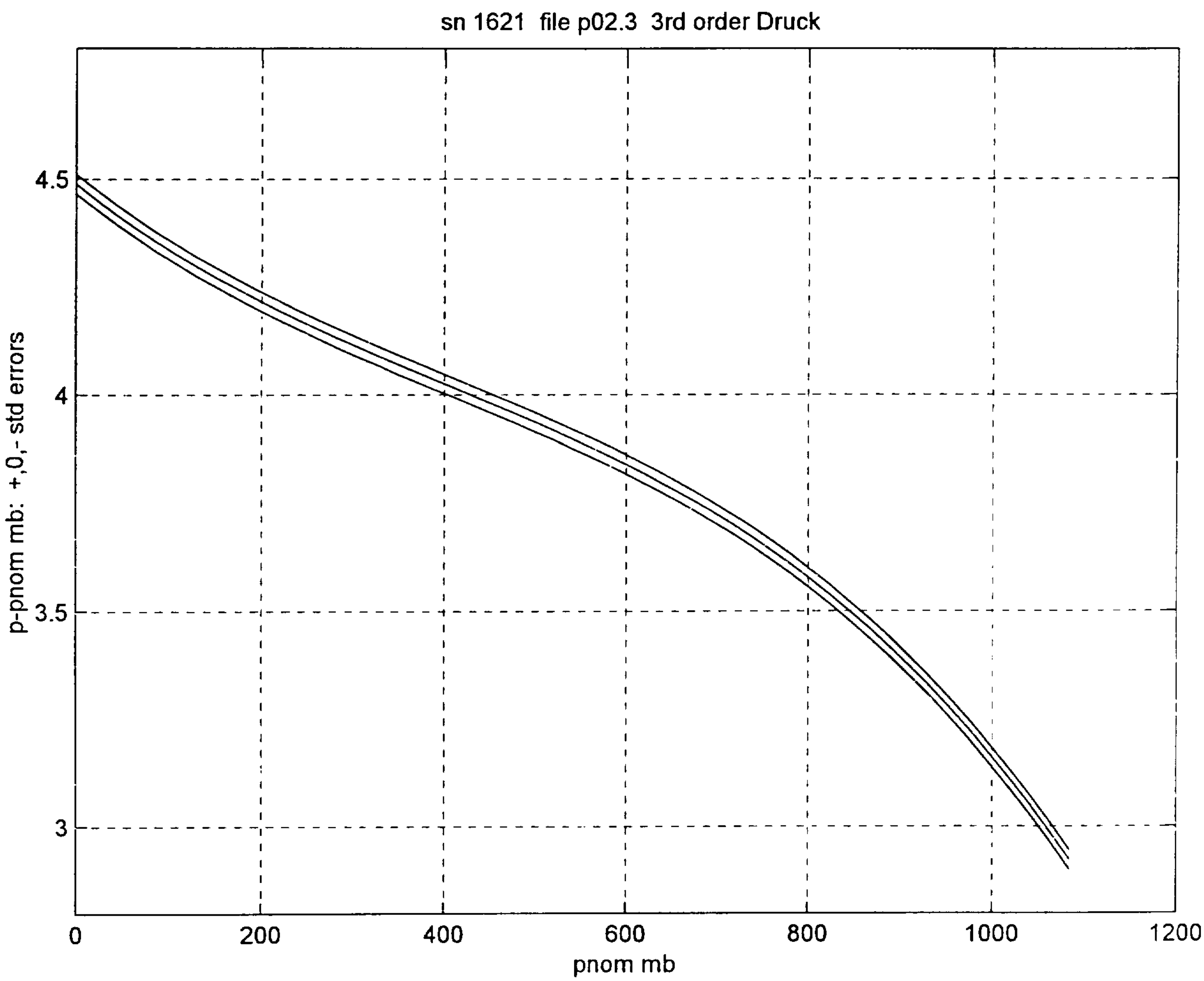
```
% p1621.m  comparison
clear
s1='sn 1621  file p02.3 2nd order Druck';
 A1 =[  4.2915966e+00      2.72e-02
   2.1666980e+02      2.30e-02
  -3.8801006e-02      4.19e-03];

s2=' sn 1621  file p02.3  3rd order Druck';
 A2 = [ 4.4885326e+00      2.23e-02
   2.1635924e+02      3.23e-02
   9.5248804e-02      1.35e-02
  -1.6806199e-02      1.68e-03];

s3='sn 1621 TC  22.36379  file p1p2_@20 3rd order';
 A3 =[  4.1012883e+00      1.0563e-02
   2.1653327e+02      1.9687e-02
   8.1149637e-02      9.9443e-03
  -1.5577792e-02      1.4206e-03];

s4='sn 1621  file \pdata\1621\1621a.085 3rd order';
 A4 =[  1.2230556e+00      3.62e-02
   2.1665375e+02      5.98e-02
   8.3997833e-02      2.68e-02
  -1.8381813e-02      3.44e-03];

s5='sn 1621  file \pdata\1621\1621b.085 3rd order';
 A5 =[  1.3675632e+00      3.66e-02
   2.1664101e+02      6.05e-02
   7.2089296e-02      2.72e-02
  -1.5518534e-02      3.48e-03];

s6='sn 1621  file \pdata\1621\1621t.085  3rd order';
 A6 = [ 1.2954031e+00      3.51e-02
   2.1664722e+02      5.81e-02
   7.8117181e-02      2.61e-02
  -1.6959508e-02      3.34e-03];

s7='sn 1621  file \pdata\1621\1621a.106  3rd order';
 A7 = [ 2.9220536e+00      4.47e-02
   2.1634102e+02      7.36e-02
   1.7717088e-01      3.29e-02
  -2.5457675e-02      4.22e-03];

s7='sn 1621  file \pdata\1621\1621b.106  3rd order';
 A7 =[  2.7232079e+00      8.25e-02
   2.1649663e+02      1.36e-01
   1.1249226e-01      6.07e-02
  -1.7918022e-02      7.79e-03];
```

```
s8='sn 1621  file \pdata\1621\1621t.106  3rd order';
 A8 =[  2.8227532e+00     5.54e-02
   2.1641864e+02     9.13e-02
   1.4490938e-01     4.08e-02
  -2.1697288e-02     5.23e-03];

   v=0:.1:5;
   Anom=216.728551;
   pnom=Anom*v;  % nominal mb for 32 " Hg

   % flip A1.. A9 up-down

   A1=flipud(A1);
   A2=flipud(A2);
   A3=flipud(A3);
   A4=flipud(A4);
   A5=flipud(A5);
   A6=flipud(A6);
   A7=flipud(A7);
   A8=flipud(A8);

   % 1st data set
   figure(1)
   A=A1(:,1);
   siga=flipud(A1(:,2));
   p0=polyval(A,v);
   dp0=p0-pnom;
   plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
   xlabel('pnom mb')
   ylabel('p-pnom mb +,0,- std errors')
   title(s1)
   grid
   pause

   figure(2)
   clear A
   A=A2(:,1);
   siga=flipud(A2(:,2));
   p0=polyval(A,v);
   dp0=p0-pnom;
   plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
   xlabel('pnom mb')
   ylabel('p-pnom mb:  +,0,- std errors')
   title(s2)
   grid
   pause
```

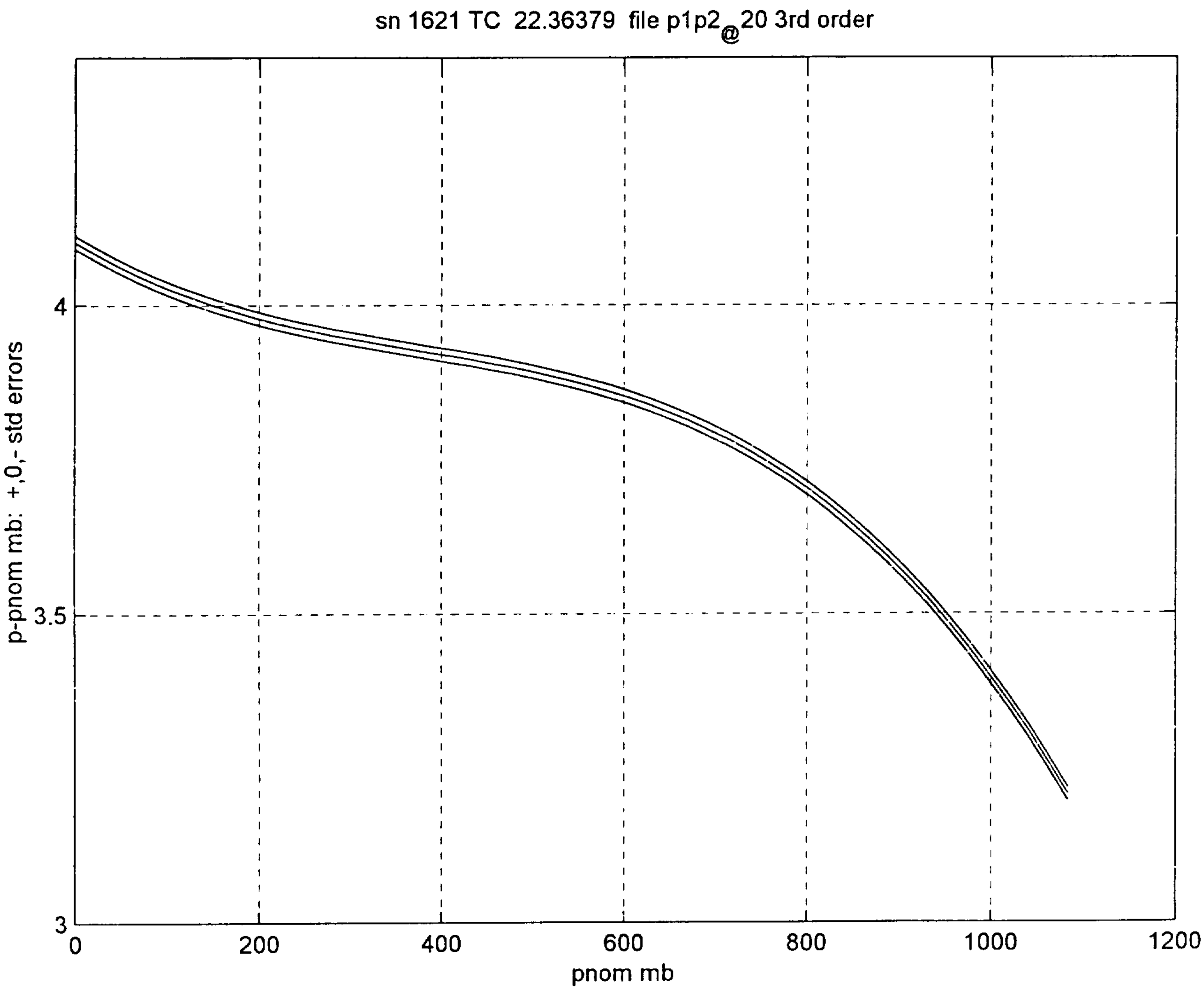
```
figure(3)
clear A
A=A3(:,1);
siga=flipud(A3(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s3)
grid
pause

figure(4)
clear A
A=A4(:,1);
siga=flipud(A4(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s4)
grid
pause

figure(5)
clear A
A=A5(:,1);
siga=flipud(A5(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s5)
grid
pause



figure(6)
clear A
A=A6(:,1);
siga=flipud(A6(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
```

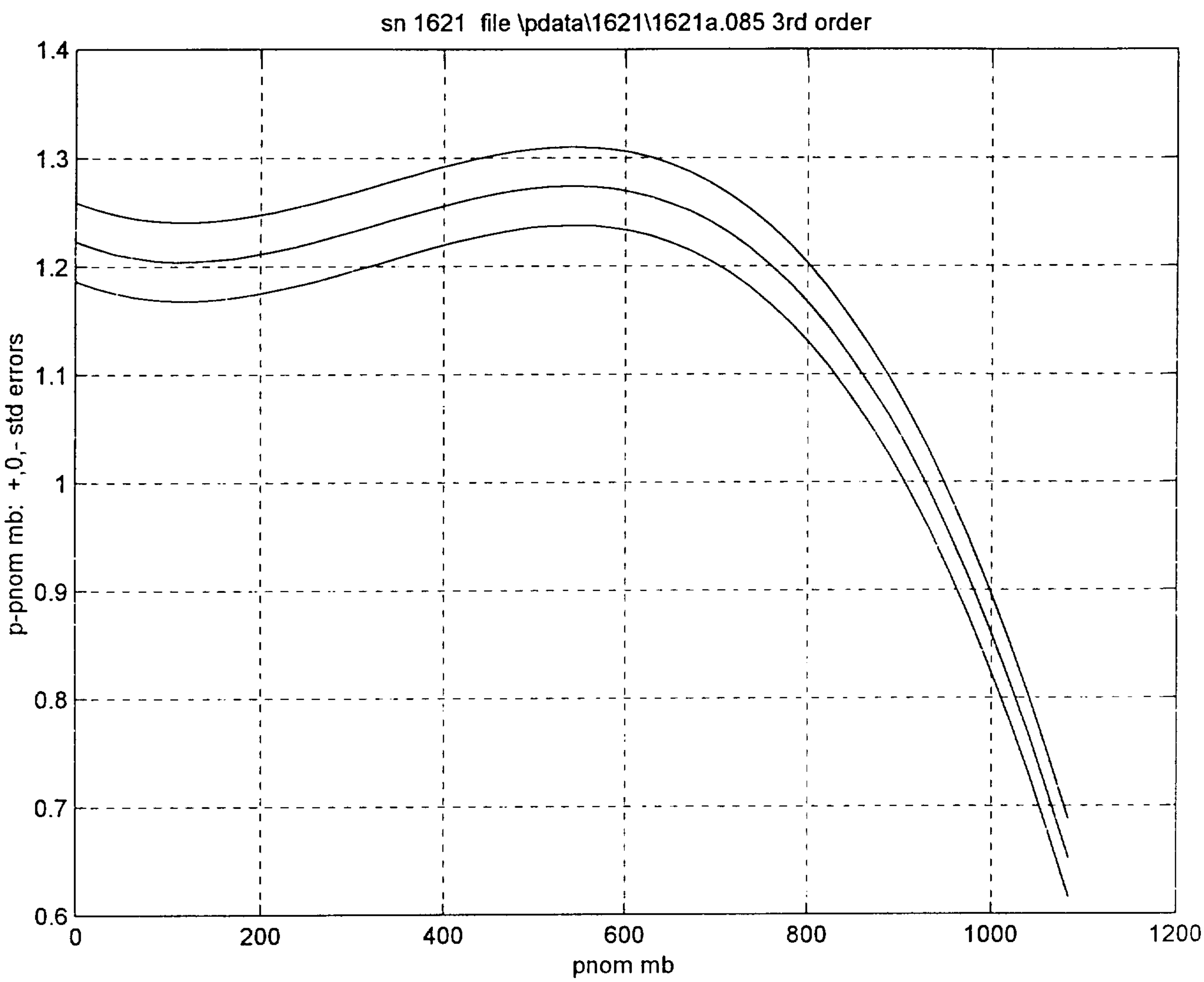
```
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s6)
grid
pause

figure(7)
clear A
A=A7(:,1);
siga=flipud(A7(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s7)
grid
pause

figure(8)
clear A
A=A8(:,1);
siga=flipud(A8(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s8)
grid
pause
```

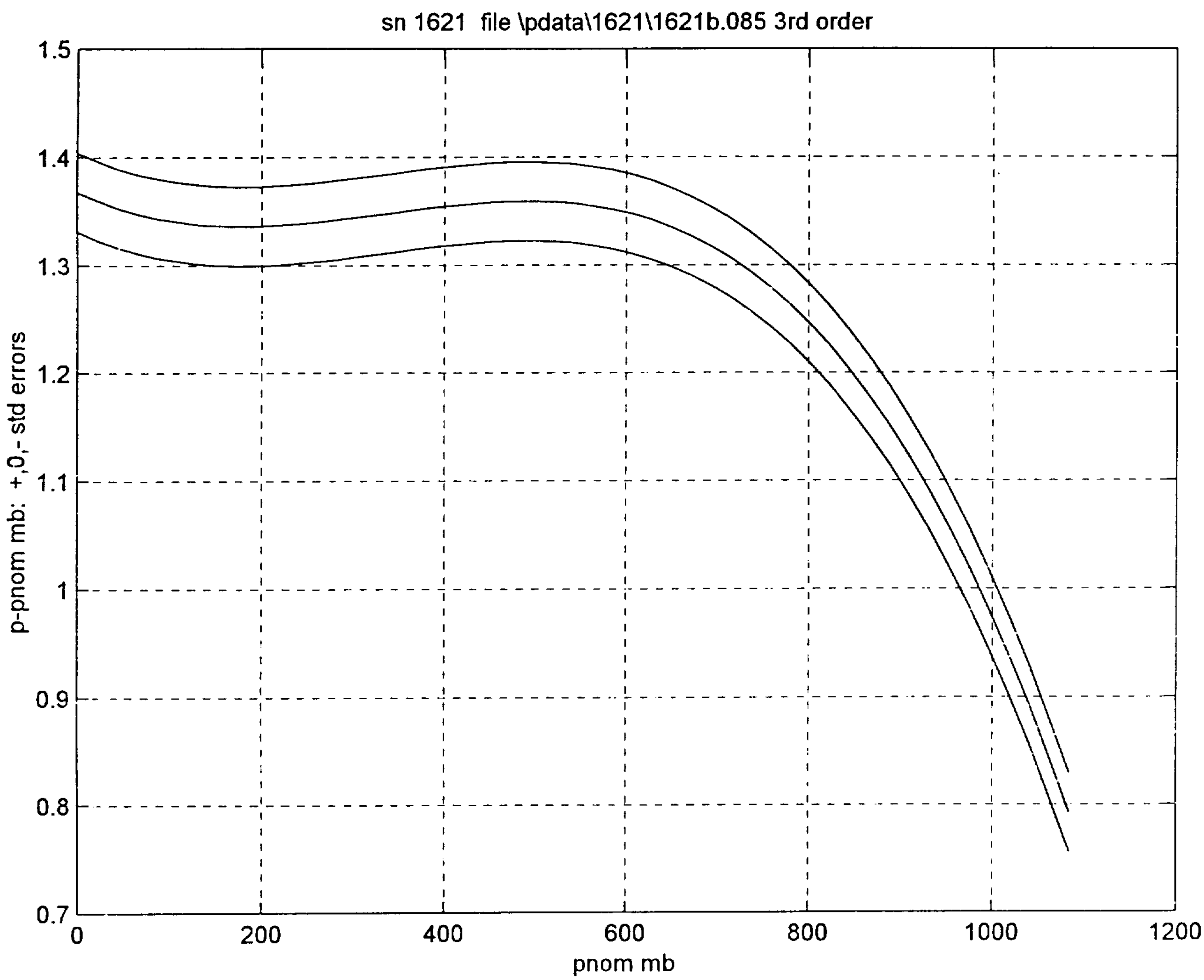

sn 1621 file p02.3 2nd order Druck
4.5
4
3.5
3
p-pnom mb +,0,- std errors
0
200
400
600
800
1000
1200
pnom mb

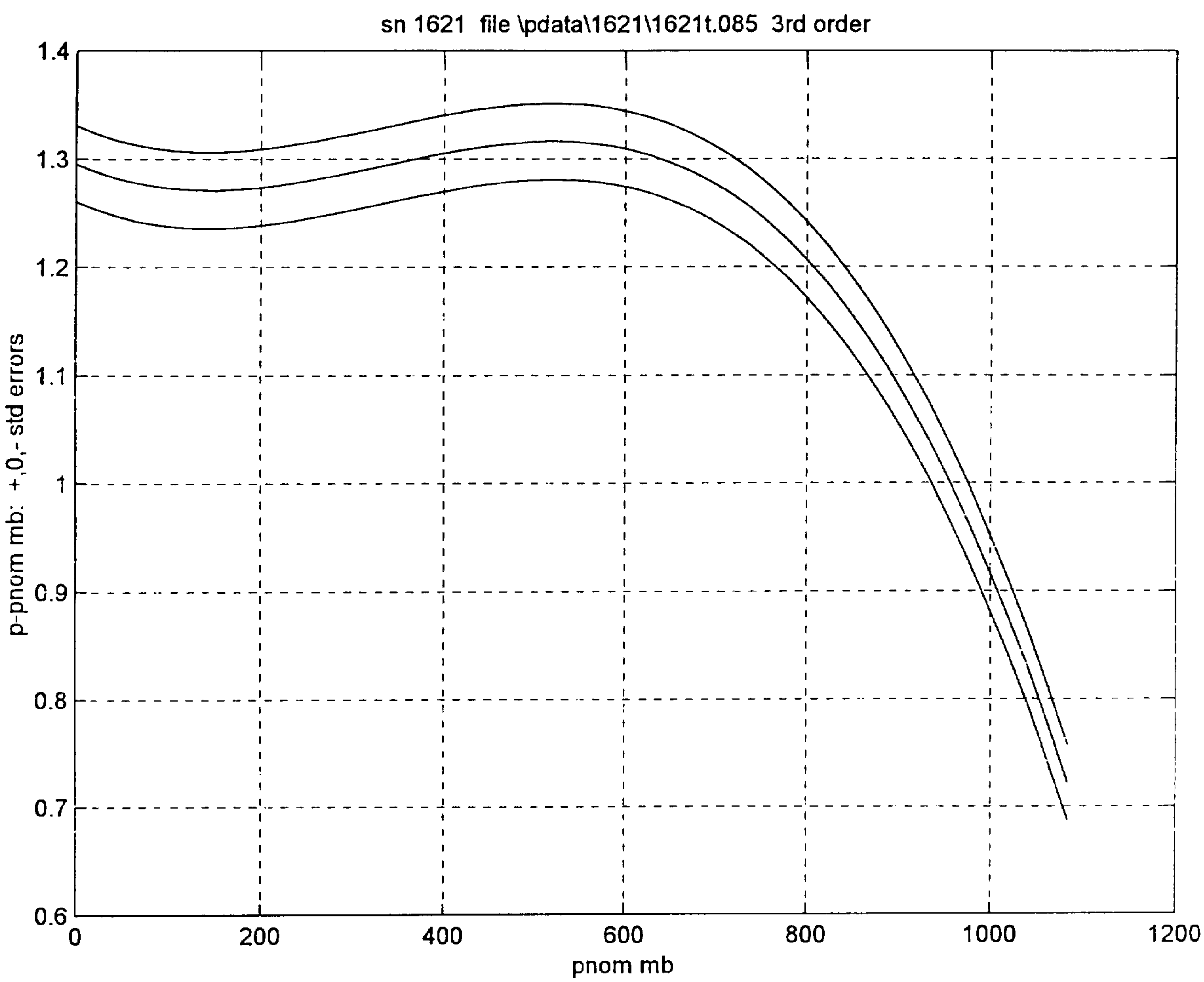


sn 1621 file p02.3 3rd order Druck
p-pnom mb: +,0,- std errors
4.5
4
3.5
3
0
200
400
600
800
1000
1200
pnom mb

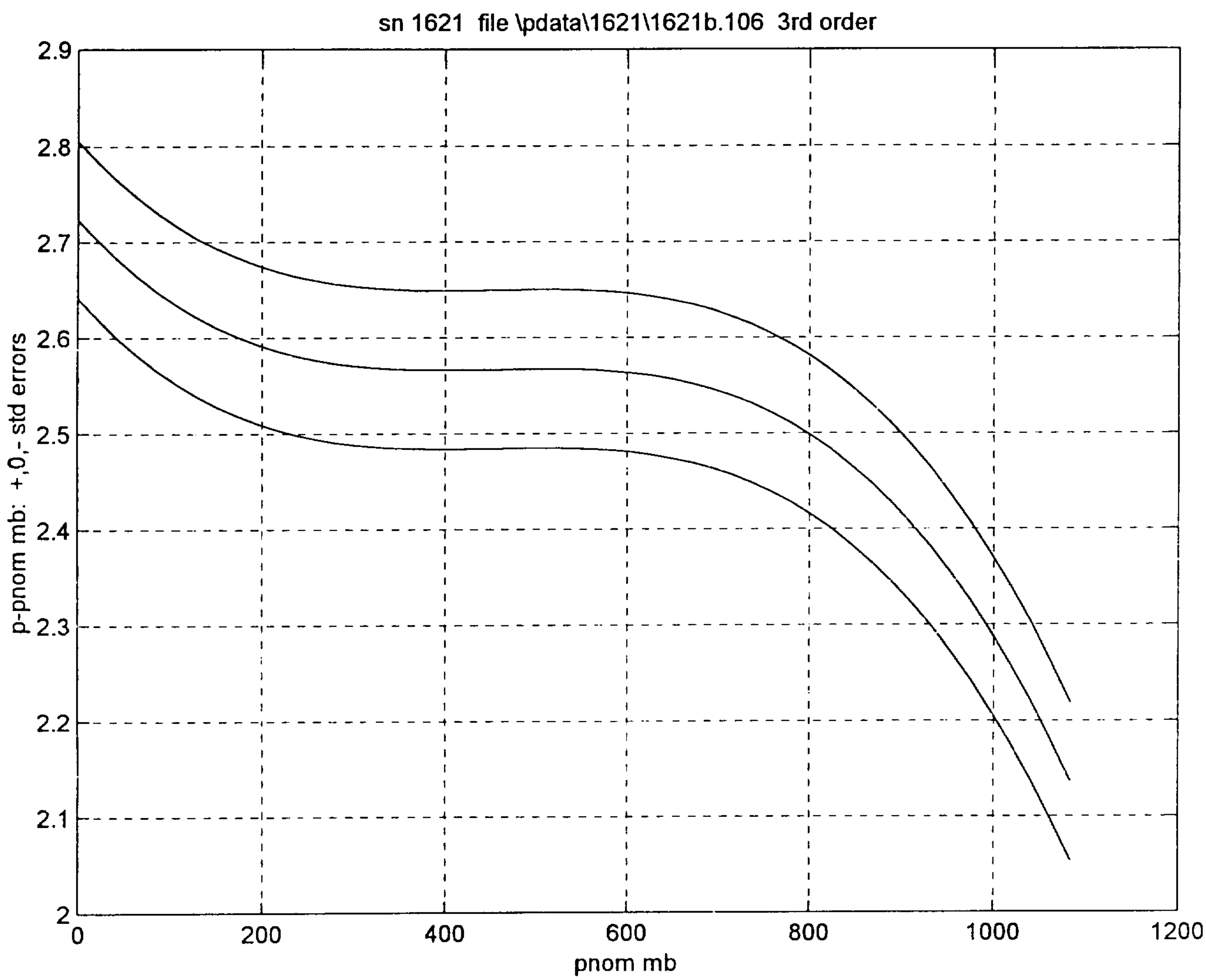

sn 1621 TC 22.36379 file p1p2_@20 3rd order
p-pnom mb: +,0,- std errors
pnom mb
4
3.5
3
0
200
400
600
800
1000
1200


sn 1621 file \pdata\1621\1621a.085 3rd order
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0
200
400
600
800
1000
1200
p-pnom mb: +,0,- std errors
pnom mb

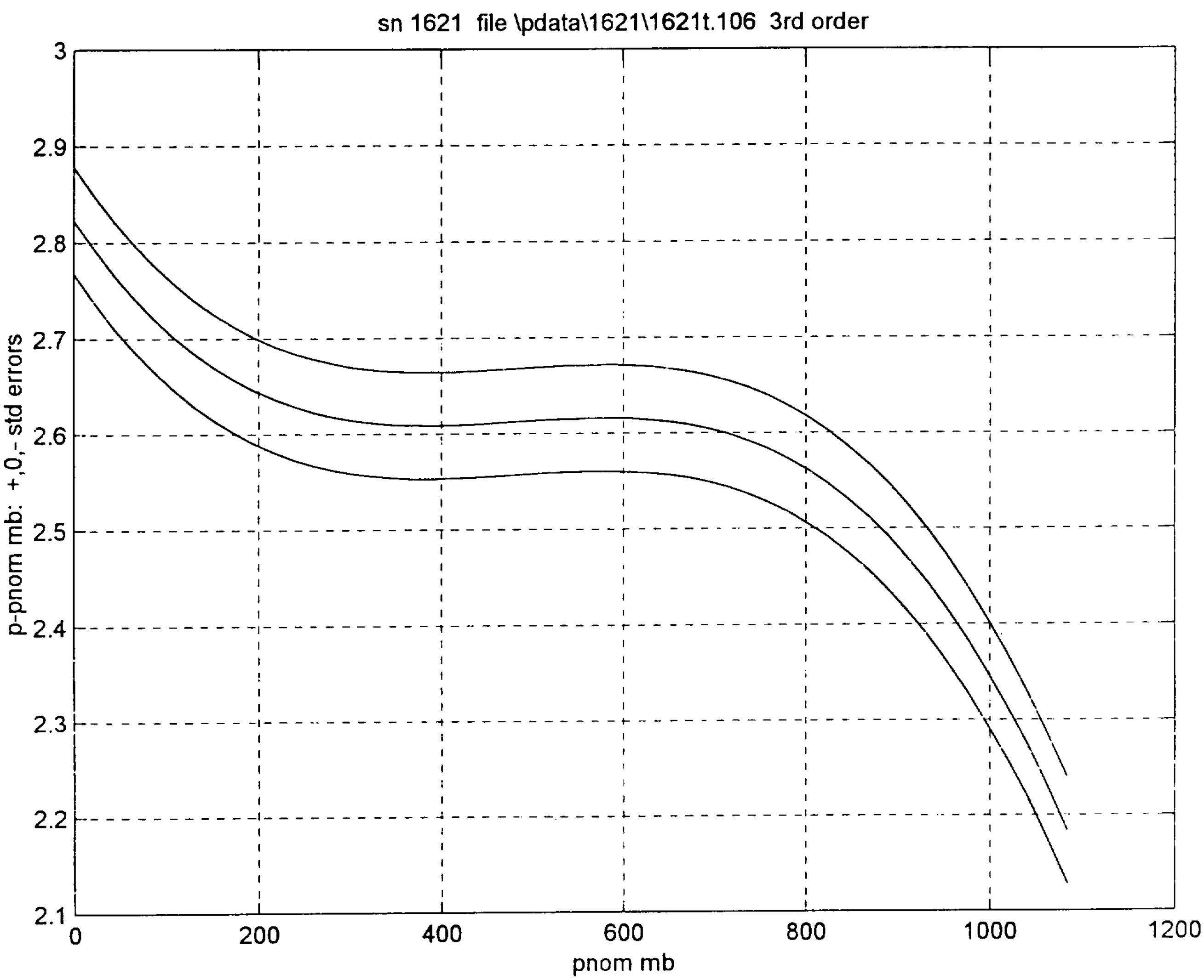

sn 1621 file \pdata\1621\1621b.085 3rd order
p-pnom mb: +,0,- std errors
pnom mb
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0
200
400
600
800
1000
1200



sn 1621 file \pdata\1621\1621t.085 3rd order
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
p-pnom mb: +,0,- std errors
0
200
400
600
800
1000
1200
pnom mb



sn 1621 file \pdata\1621\1621b.106 3rd order
p-pnom mb: +,0,- std errors
pnom mb
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
0
200
400
600
800
1000
1200


sn 1621 file \pdata\1621\1621t.106 3rd order
p-pnom mb: +,0,- std errors
pnom mb
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
0
200
400
600
800
1000
1200

```
% p1616.m  comparison
clear
  s1='sn 1616  file p01.1 1st order Druck';
   A1 =[ -2.0342887e+00     4.86e-02
     6.9164525e+01     1.39e-02];

  s2='sn 1616  file p01.1  2nd order Druck';
   A2 =[ -1.4754169e+00     2.25e-01
     6.8832652e+01     1.33e-01
     4.6267341e-02     1.85e-02];

  s3='sn 1616  file p01.1  3rd order Druck';
   A3 =[ -1.0421235e+00     1.79e+00
     6.8457016e+01     1.54e+00
     1.5177678e-01     4.29e-01
    -9.6310826e-03     3.91e-02];

 s4='sn 1616 TC  22.34337  file p1p2_@20  3rd order';
   A4 =[ -1.3062232e+00     3.7320e-02
     6.8812810e+01     5.1664e-02
     6.5179720e-02     2.0906e-02
    -1.9783920e-03     2.5492e-03];

 s5='sn 1616 TC  16.14556  file t_15c.asc   3rd order';
   A5 =[  5.3157683e-01     6.8816e-02
     6.8841790e+01     9.5360e-02
     1.9044815e-02     3.8611e-02
     4.3282708e-03     4.7098e-03];

  s6='sn 1616  file \pdata\1616\1616a.085  3rd order';
   A6 =[  1.1161150e+00     2.02e-02
     6.8649015e+01     3.31e-02
     1.0336928e-01     1.49e-02
    -7.0159573e-03     1.91e-03];

  s7='sn 1616  file \pdata\1616\1616b.085  3rd order';
   A7 =[  1.1403682e+00     1.41e-02
     6.8578857e+01     2.31e-02
     1.2917200e-01     1.04e-02
    -9.9299392e-03     1.33e-03];

  s8='sn 1616  file \pdata\1616\1616t.085  3rd order';
   A8 = [ 1.1282501e+00     1.45e-02
     6.8613919e+01     2.38e-02
     1.1627955e-01     1.07e-02
    -8.4742723e-03     1.37e-03];

  s9='sn 1616  file \pdata\1616\1616a.086  3rd order';
```

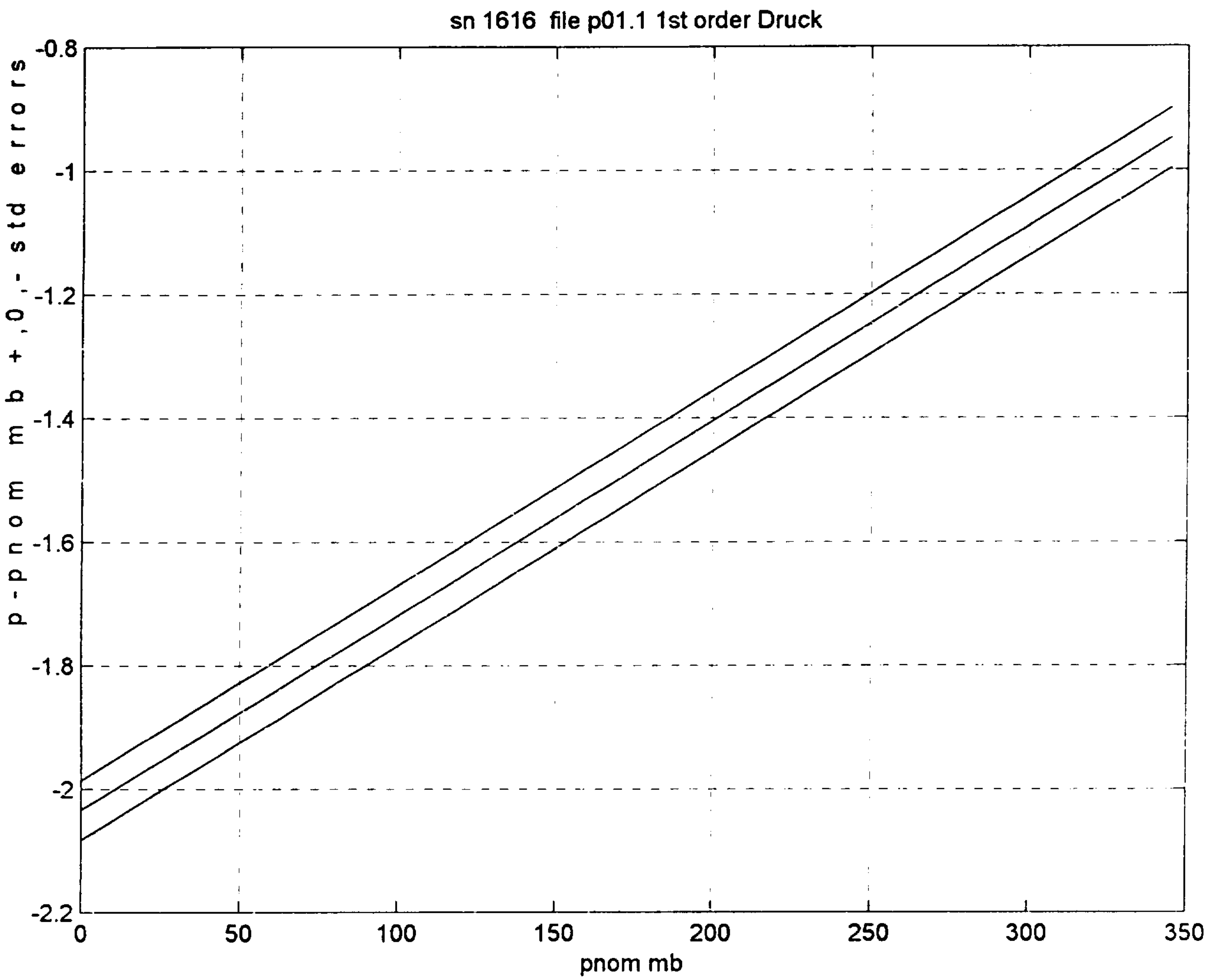
```
 A9 =[  3.1190773e-01     3.70e-02
   6.9005438e+01     5.28e-02
  -3.4469315e-02     2.15e-02
   8.9067393e-03     2.58e-03];

s10='sn 1616  file \pdata\1616\1616b.086  3rd order';
 A10 =[  3.0911100e-01     3.51e-02
   6.9010719e+01     5.01e-02
  -3.7982301e-02     2.04e-02
   9.5184661e-03     2.45e-03];

s11='sn 1616  file \pdata\1616\1616t.086 3rd order';
 A11 =[  3.1051072e-01     2.49e-02
   6.9008076e+01     3.56e-02
  -3.6224641e-02     1.45e-02
   9.2124461e-03     1.74e-03];

s12='sn 1616  file \pdata\1616\1616a.106  3rd order';
 A12 =[  6.9478759e-01     3.70e-02
   6.8465538e+01     6.07e-02
   1.6127949e-01     2.71e-02
  -1.3025883e-02     3.47e-03];

s13='sn 1616  file \pdata\1616\1616b.106  3rd order';
 A13 =[  4.3083494e-01     3.78e-02
   6.8601901e+01     6.20e-02
   1.1515427e-01     2.76e-02
  -8.0808769e-03     3.54e-03];

s14='sn 1616  file \pdata\1616\1616t.106  3rd order';
 A14 =[  5.6351001e-01     5.01e-02
   6.8532651e+01     8.22e-02
   1.3865431e-01     3.67e-02
  -1.0605926e-02     4.70e-03];

  v=0:.1:5;
  Anom=68.94733;
  pnom=Anom*v;  % nominal mb for 5 psi

  % flip A1.. A14 up-down

  A1=flipud(A1);
  A2=flipud(A2);
  A3=flipud(A3);
  A4=flipud(A4);
  A5=flipud(A5);
  A6=flipud(A6);
  A7=flipud(A7);
```

```
A8=flipud(A8);
A9=flipud(A9);
A10=flipud(A10);
A11=flipud(A11);
A12=flipud(A12);
A13=flipud(A13);
A14=flipud(A14);

% 1st data set
figure(1)
A=A1(:,1);
siga=flipud(A1(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb +,0,- std errors')
title(s1)
grid
pause

figure(2)
clear A
A=A2(:,1);
siga=flipud(A2(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s2)
grid
pause

figure(3)
clear A
A=A3(:,1);
siga=flipud(A3(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s3)
grid
pause

figure(4)
```

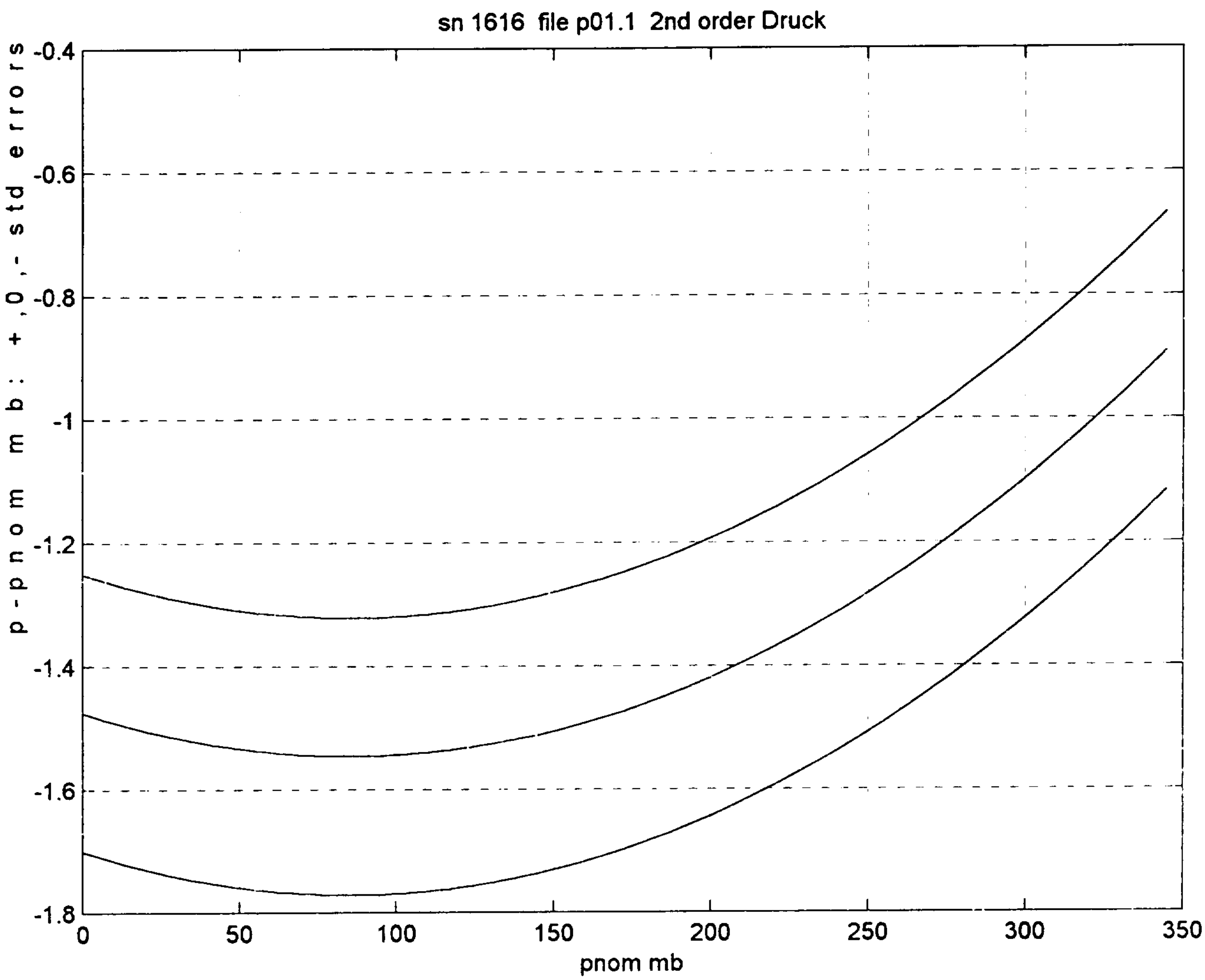
```
clear A
A=A4(:,1);
siga=flipud(A4(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s4)
grid
pause

figure(5)
clear A
A=A5(:,1);
siga=flipud(A5(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s5)
grid
pause



figure(6)
clear A
A=A6(:,1);
siga=flipud(A6(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s6)
grid
pause

figure(7)
clear A
A=A7(:,1);
siga=flipud(A7(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
```

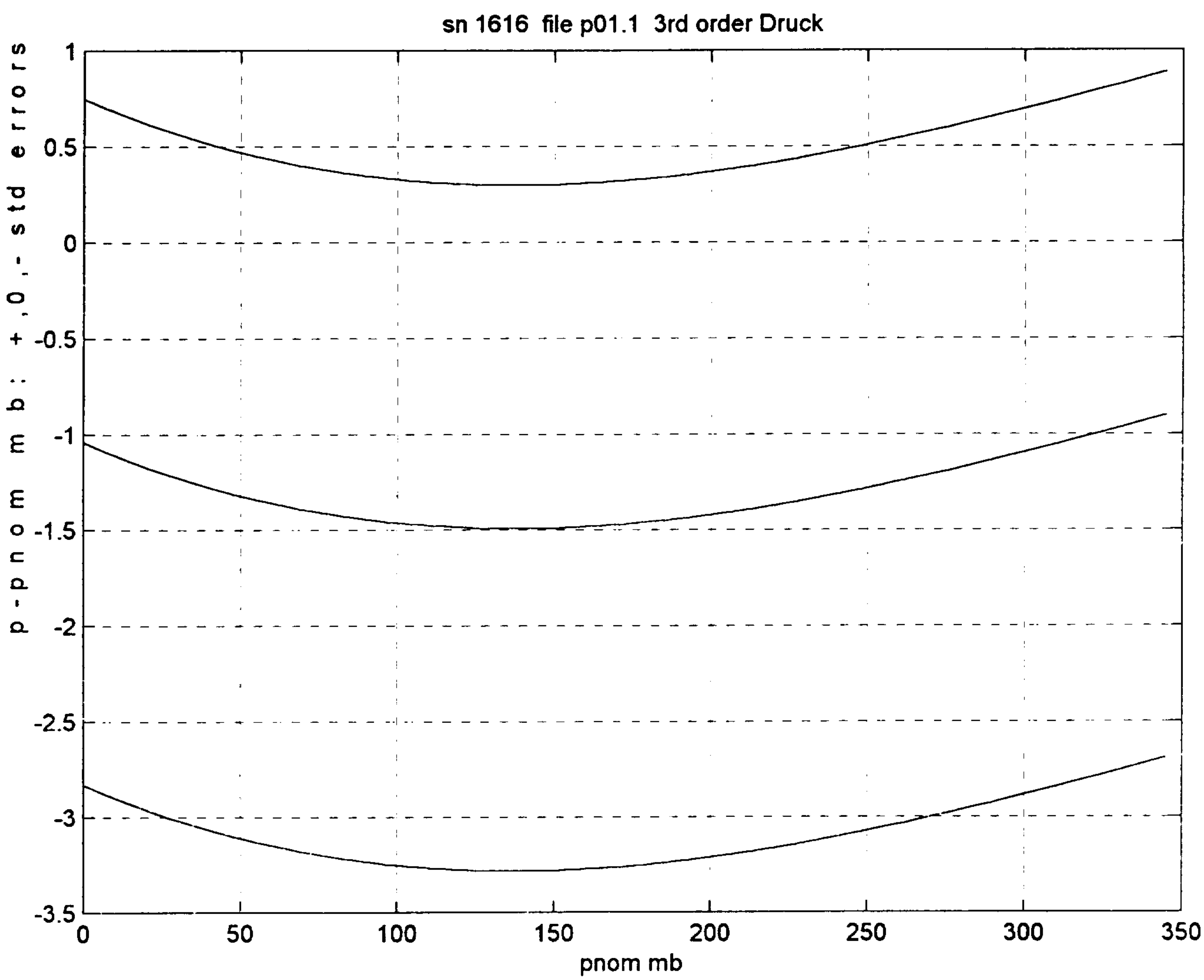
```
ylabel('p-pnom mb:  +,0,- std errors')
title(s7)
grid
pause

figure(8)
clear A
A=A8(:,1);
siga=flipud(A8(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s8)
grid
pause

figure(9)
clear A
A=A9(:,1);
siga=flipud(A9(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb +,0,- std errors')
title(s9)
grid
pause

figure(10)
clear A
A=A10(:,1);
siga=flipud(A10(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s10)
grid
pause

figure(11)
clear A
A=A11(:,1);
siga=flipud(A11(:,2));
```

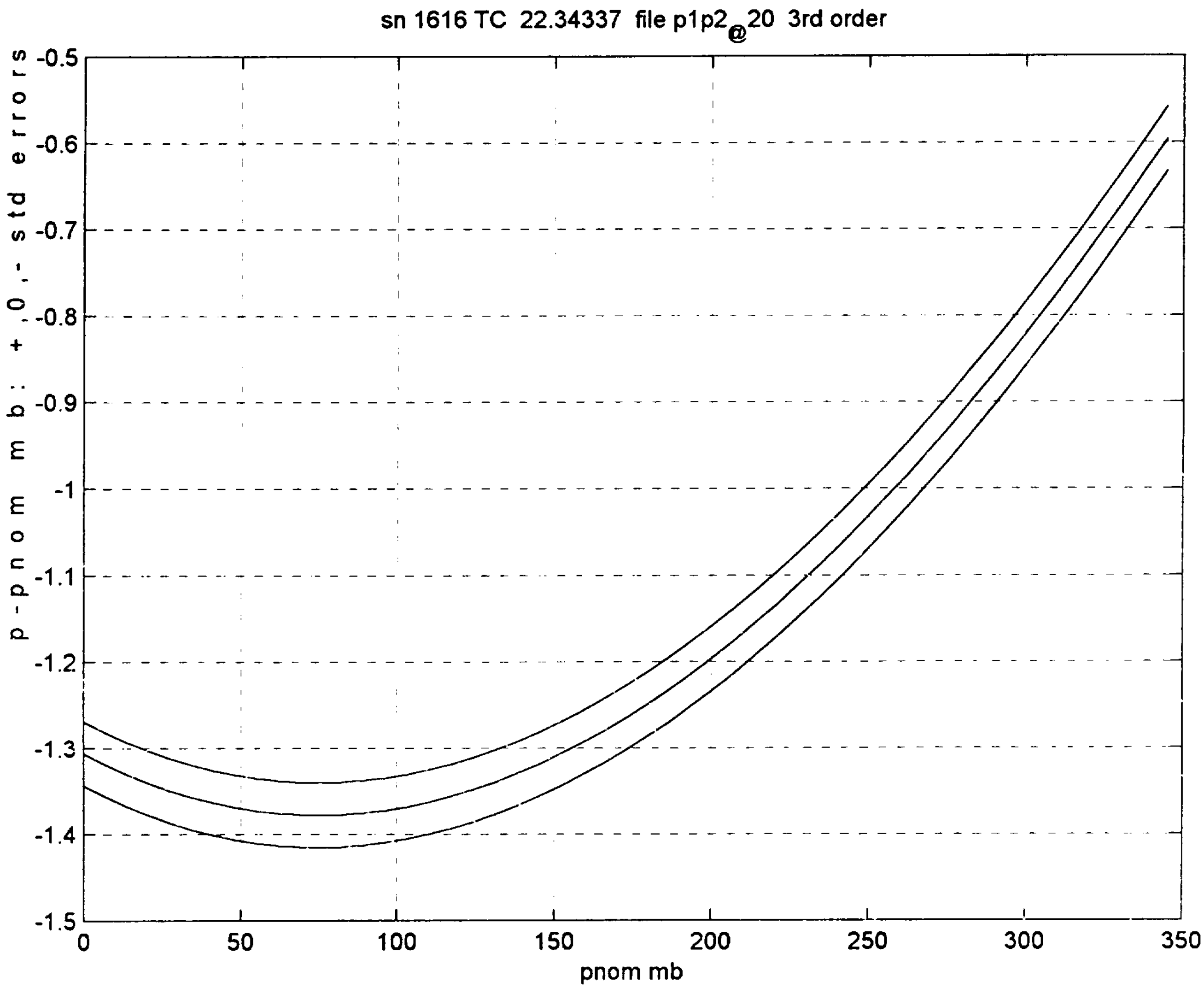
```
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s11)
grid
pause

figure(12)
clear A
A=A12(:,1);
siga=flipud(A12(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s12)
grid
pause

figure(13)
clear A
A=A13(:,1);
siga=flipud(A13(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s13)
grid
pause

figure(14)
clear A
A=A14(:,1);
siga=flipud(A14(:,2));
p0=polyval(A,v);
dp0=p0-pnom;
plot(pnom,dp0-siga(1),pnom,dp0,pnom,dp0+siga(1))
xlabel('pnom mb')
ylabel('p-pnom mb:  +,0,- std errors')
title(s14)
grid
```



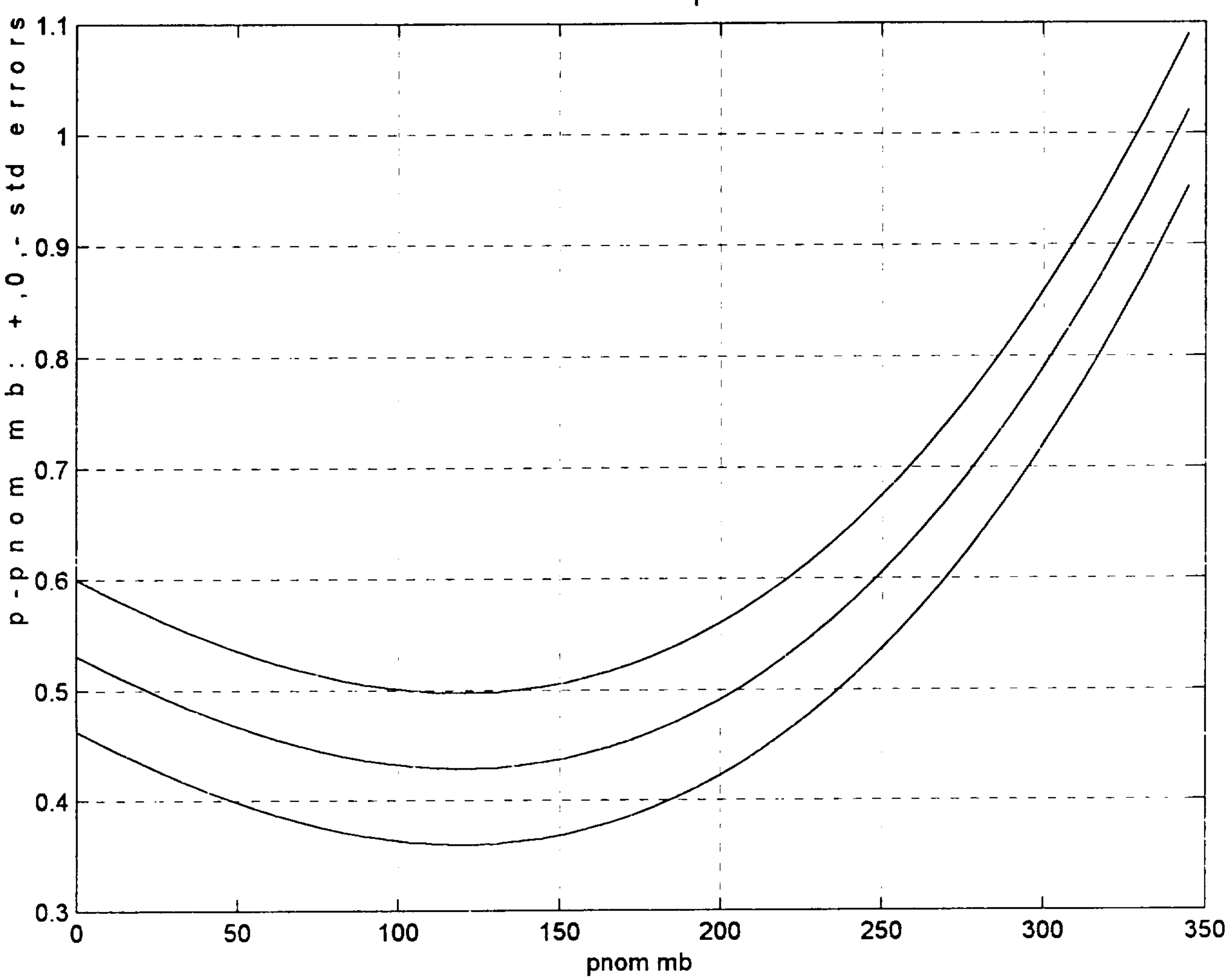
sn 1616 file p01.1 1st order Druck
p - p n o m m b + , 0 , - s t d e r r o r s
pnom mb
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
0
50
100
150
200
250
300
350

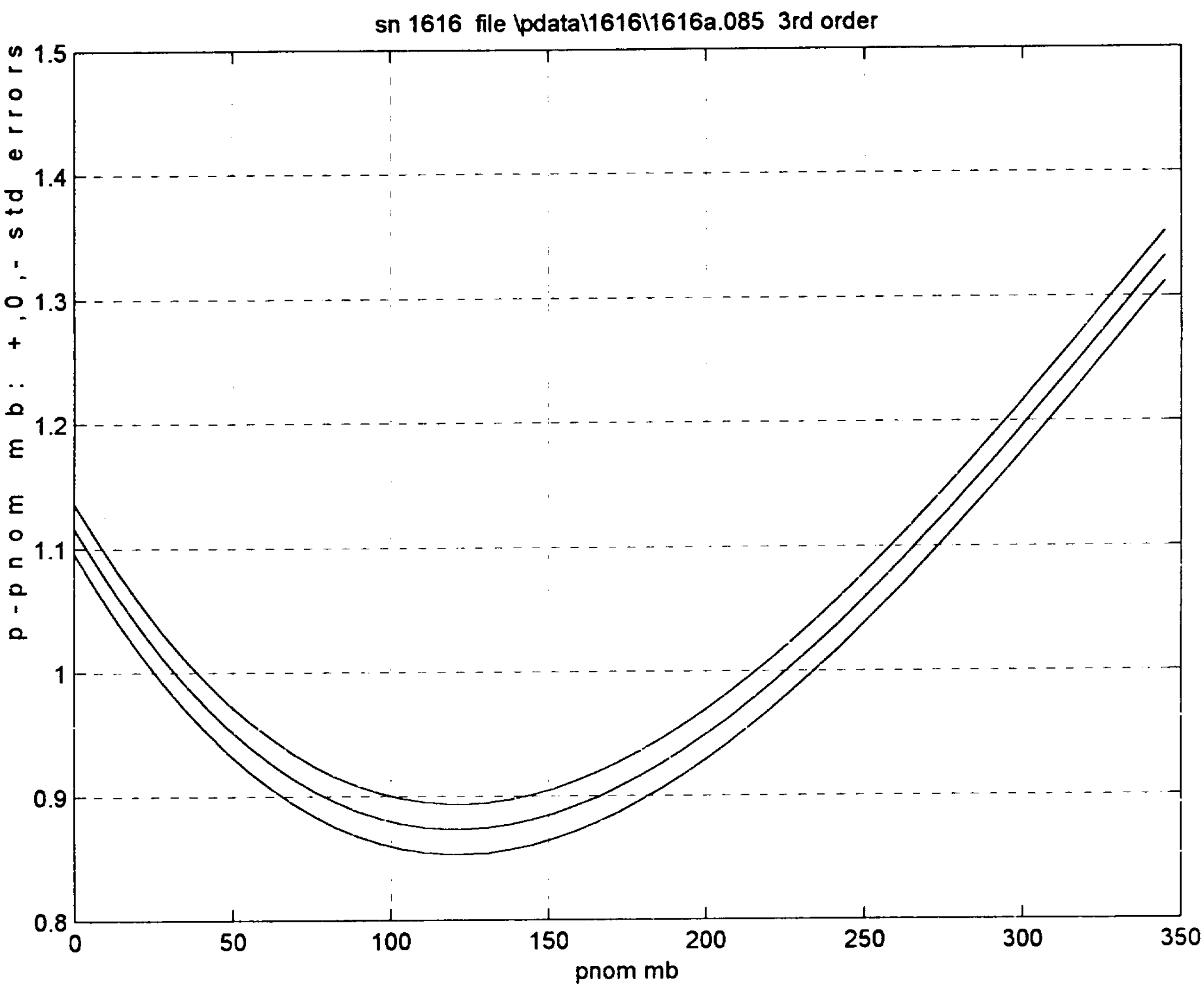

sn 1616 file p01.1 2nd order Druck
p - pnom mb: +,0,- std errors
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
0
50
100
150
200
250
300
350
pnom mb

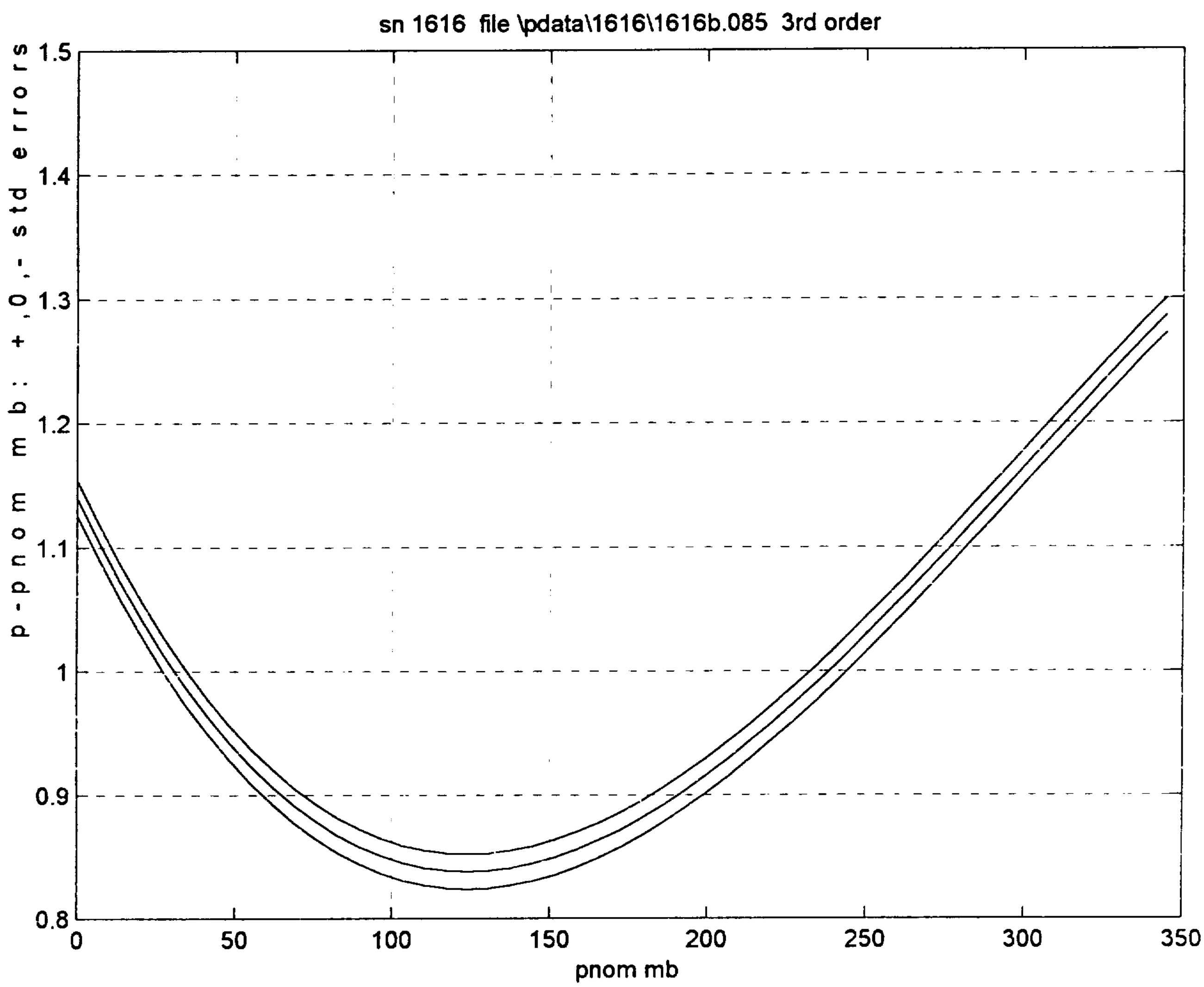

sn 1616 file p01.1 3rd order Druck
p - p n o m m b : + , 0 , - s t d e r r o r s
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
0
50
100
150
200
250
300
350
pnom mb


sn 1616 TC 22.34337 file p1p2@20 3rd order
p - pnom mb : + , 0 , - std errors
pnom mb
-0.5
-0.6
-0.7
-0.8
-0.9
-1
-1.1
-1.2
-1.3
-1.4
-1.5
0
50
100
150
200
250
300
350

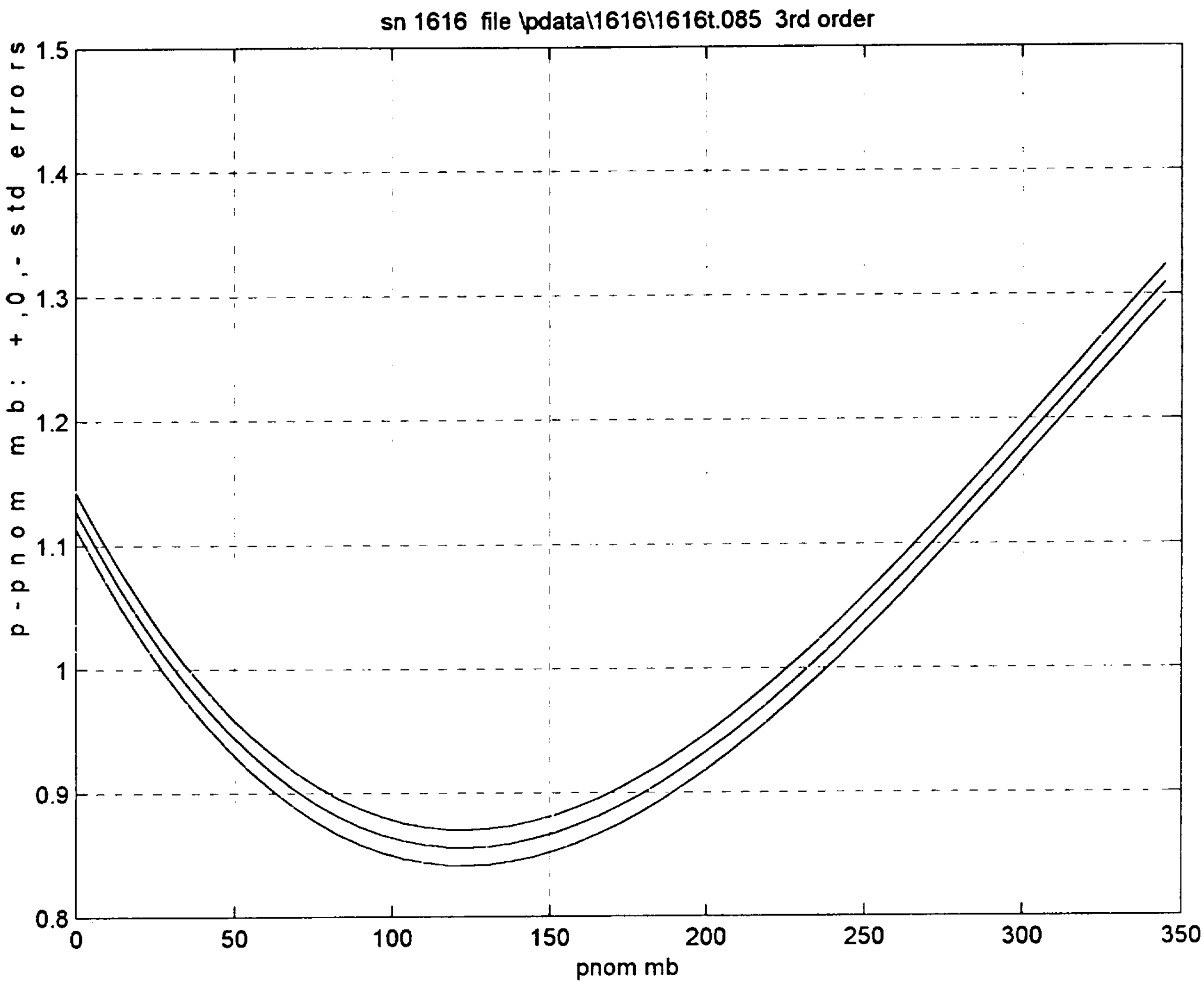
sn 1616 TC 16.14556 file $t_1$5c.asc   3rd order

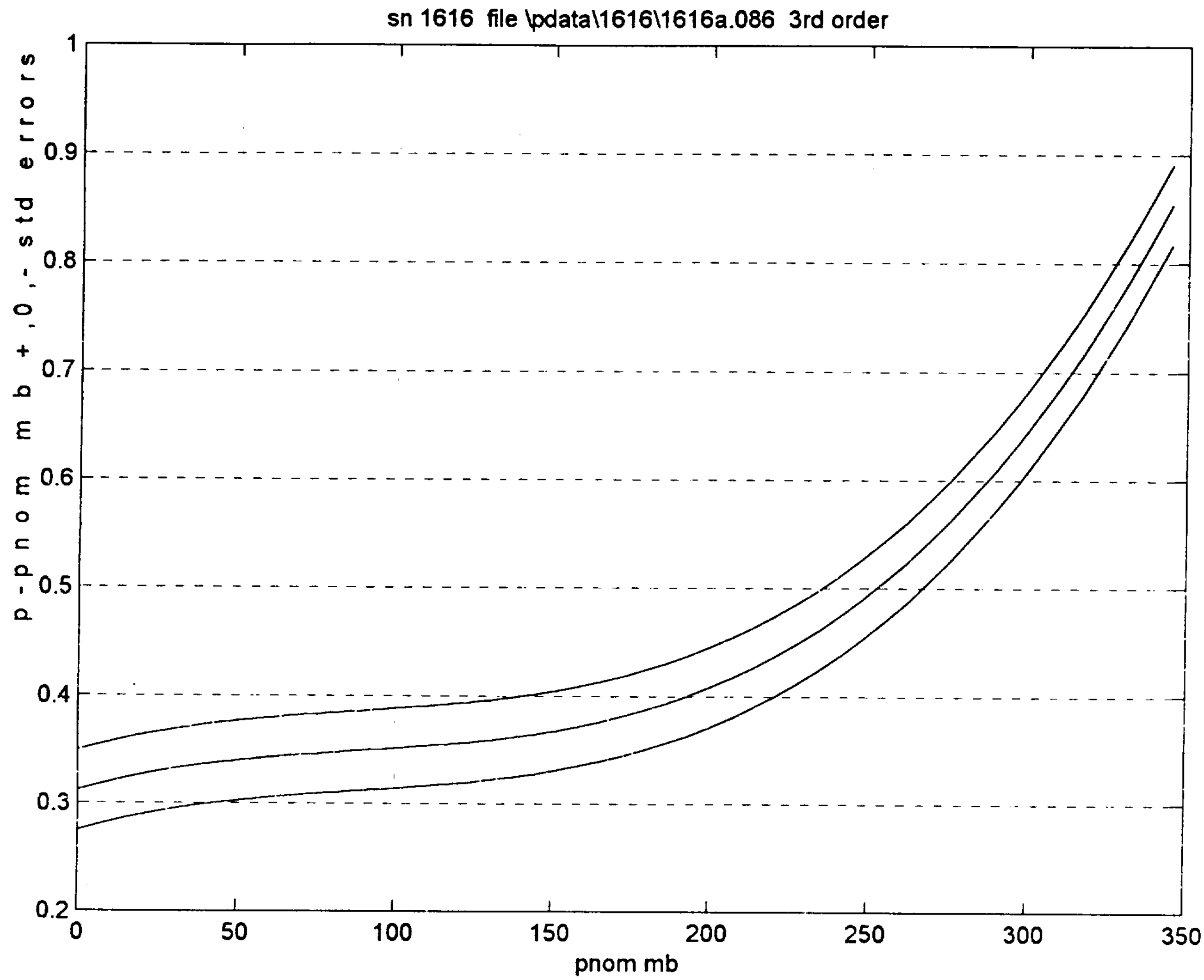


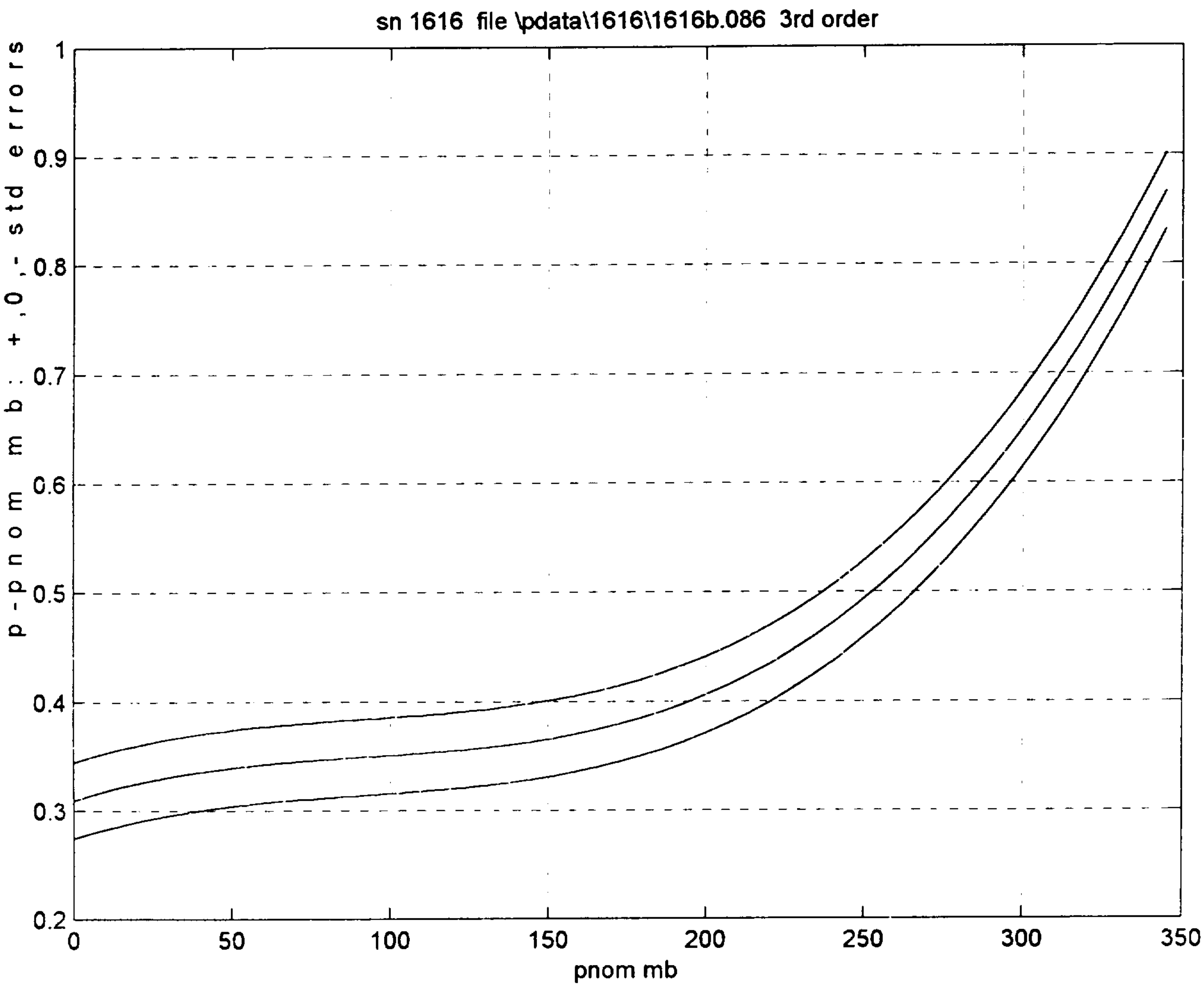

sn 1616 file \pdata\1616\1616a.085 3rd order
p - p n o m m b : + , 0 , - s t d e r r o r s
pnom mb
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350

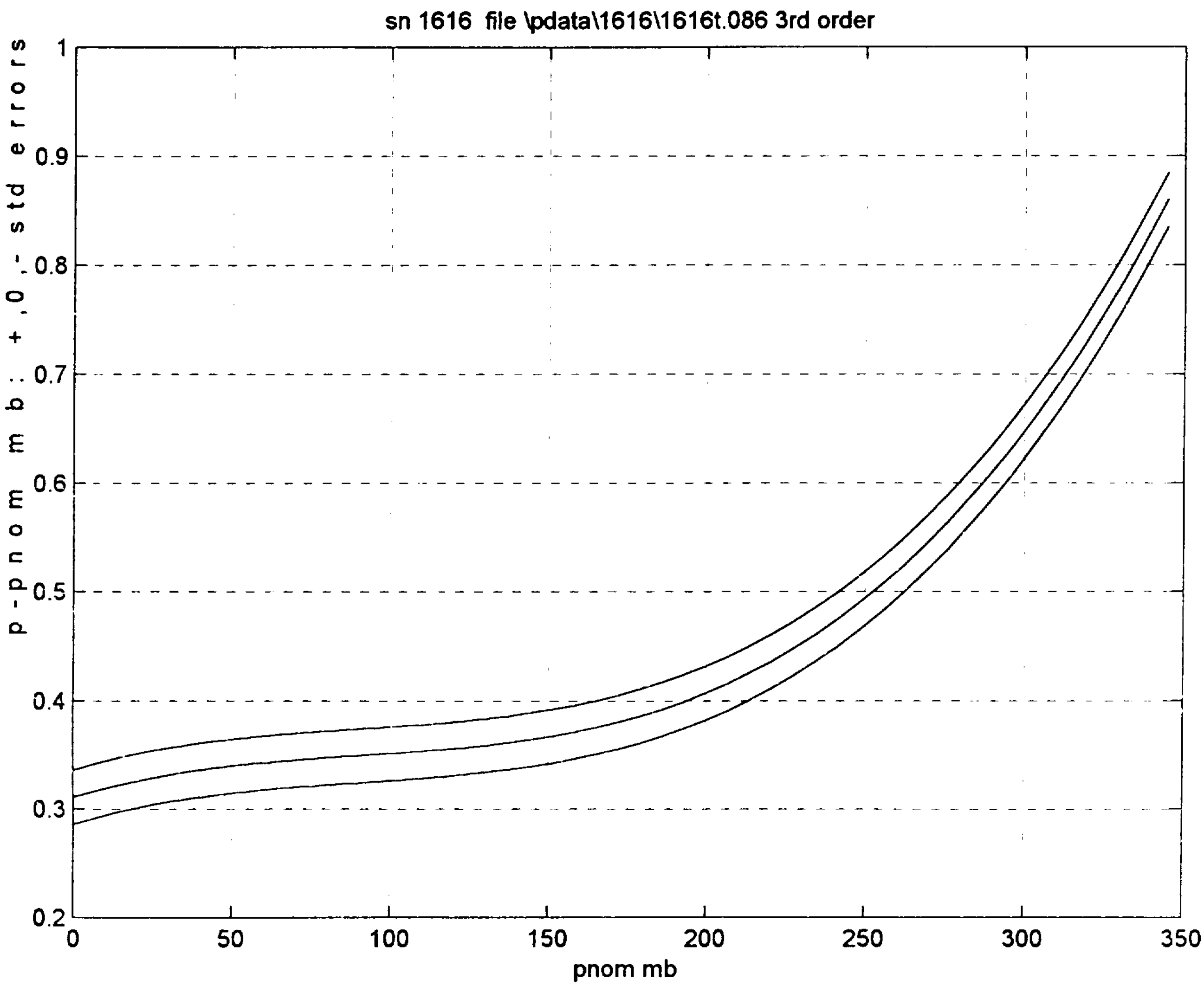


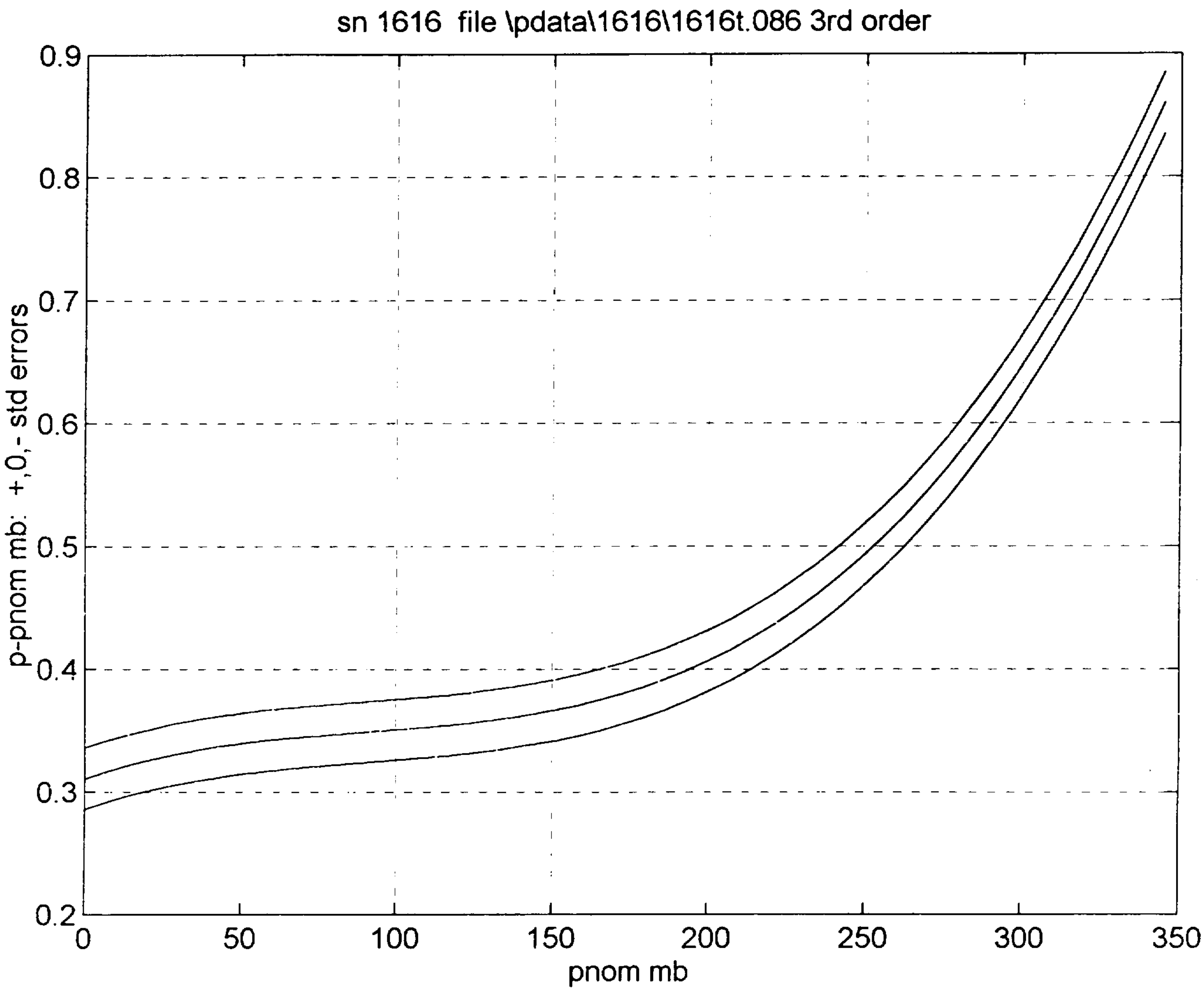
sn 1616 file \pdata\1616\1616b.085 3rd order
p - p n o m m b : + , 0 , - s t d e r r o r s
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0
50
100
150
200
250
300
350
pnom mb


sn 1616 file \pdata\1616\1616t.085 3rd order
p-pnom mb: +,0,- std errors
pnom mb
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0
50
100
150
200
250
300
350

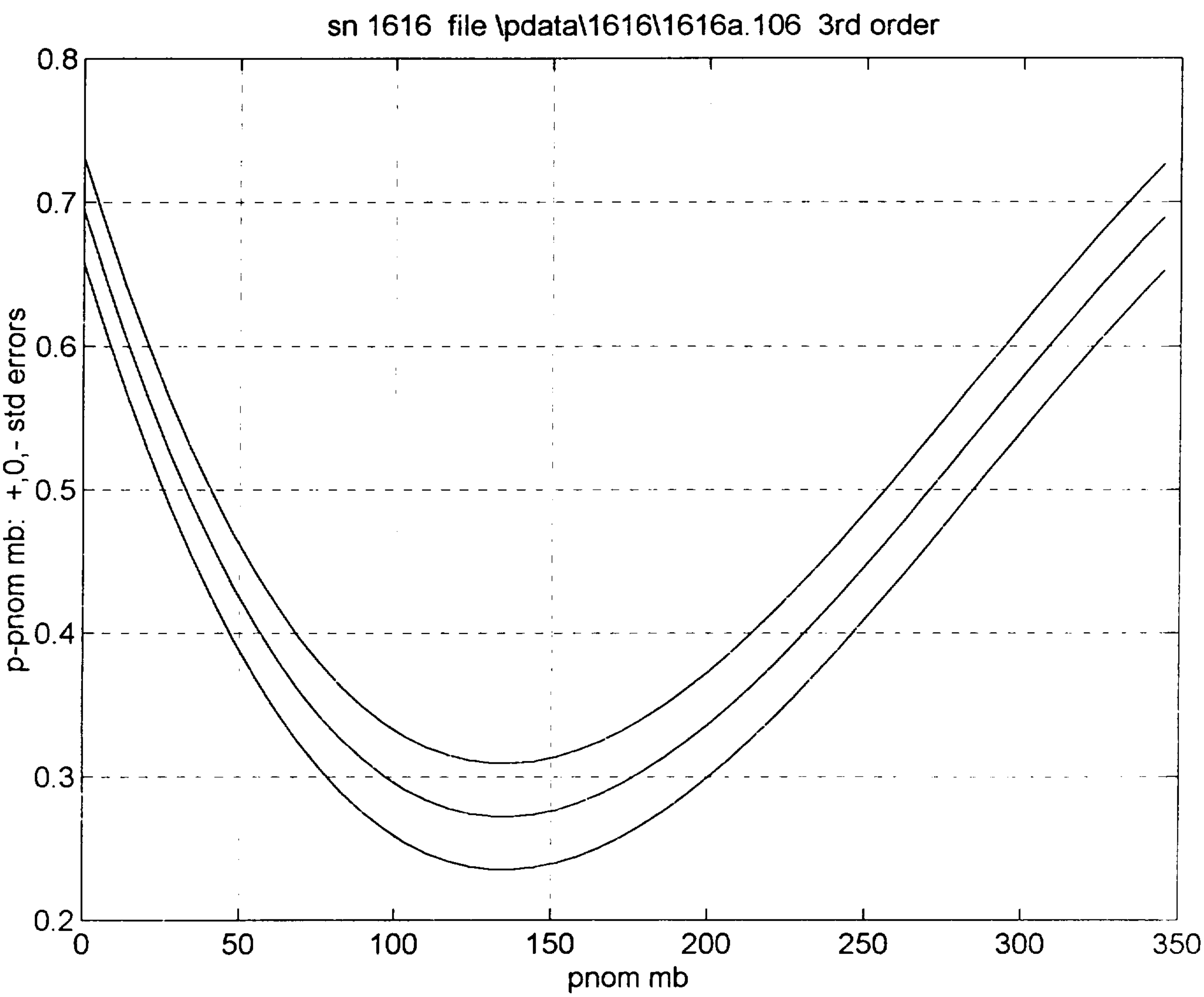

sn 1616 file \pdata\1616\1616a.086 3rd order
p - p n o m m b + , 0 , - s t d e r r o r s
pnom mb
0
50
100
150
200
250
300
350
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

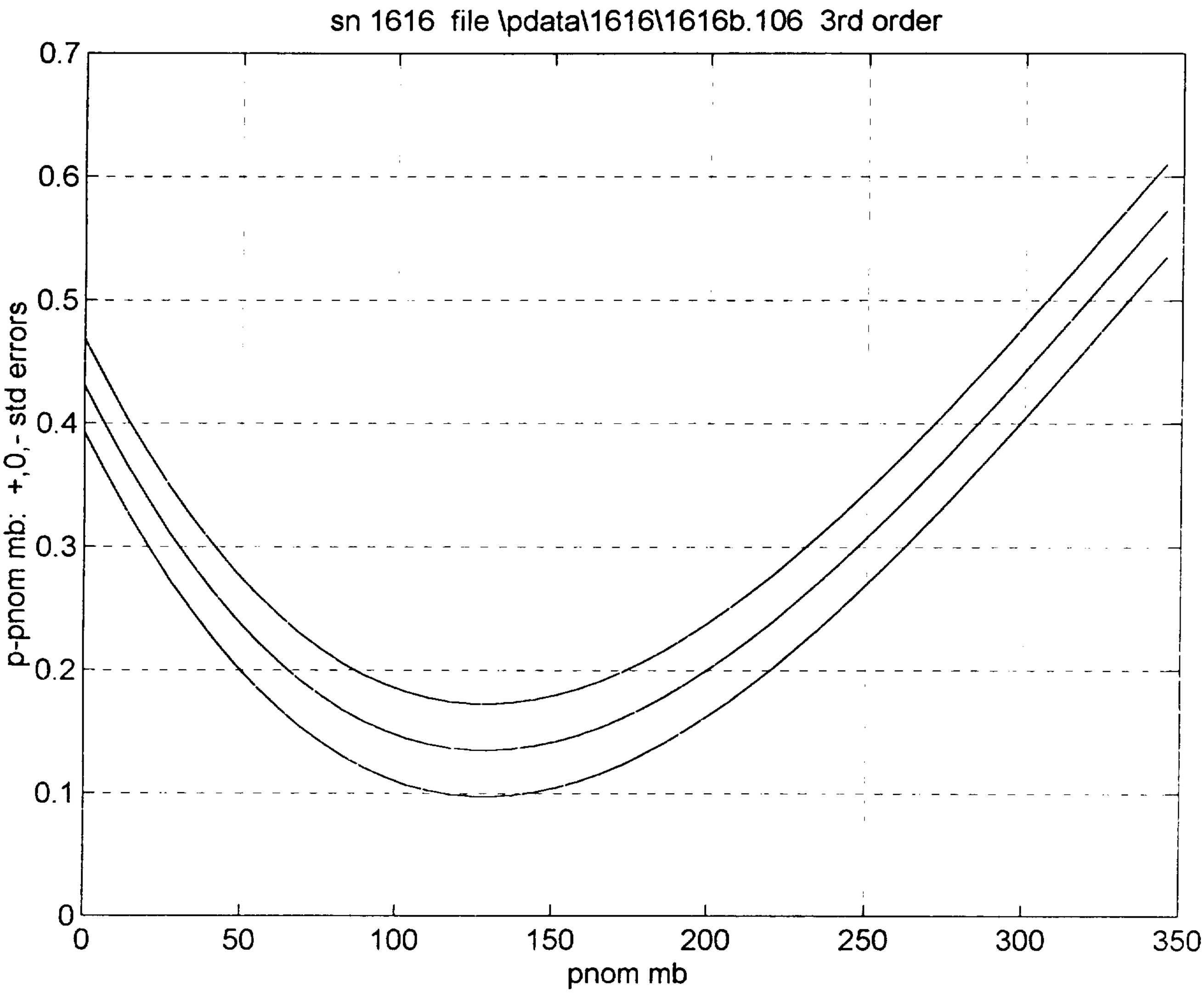

sn 1616 file \pdata\1616\1616b.086 3rd order
p - pnom mb : + , 0 , - std errors
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
50
100
150
200
250
300
350
pnom mb

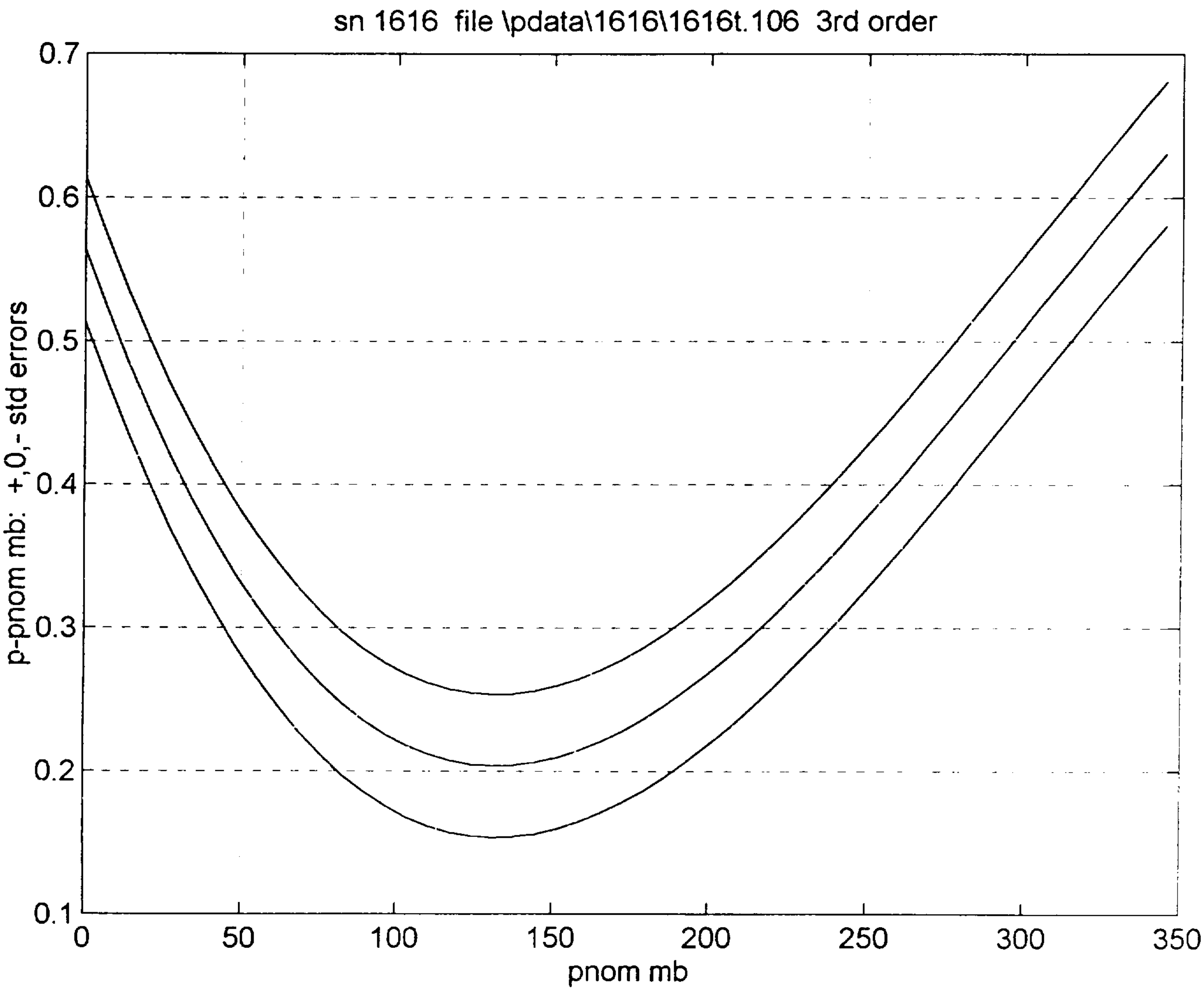

sn 1616 file \pdata\1616\1616t.086 3rd order
p - p n o m m b : + , 0 , - s t d e r r o r s
pnom mb
0
50
100
150
200
250
300
350
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



sn 1616 file \pdata\1616\1616t.086 3rd order
p-pnom mb: +,0,- std errors
pnom mb
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
50
100
150
200
250
300
350


sn 1616 file \pdata\1616\1616a.106 3rd order
p-pnom mb: +,0,- std errors
pnom mb
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
50
100
150
200
250
300
350


sn 1616 file \pdata\1616\1616b.106 3rd order
p-pnom mb: +,0,- std errors
pnom mb
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
50
100
150
200
250
300
350


sn 1616 file \pdata\1616\1616t.106 3rd order
0.7
0.6
0.5
0.4
0.3
0.2
0.1
p-pnom mb: +,0,- std errors
0
50
100
150
200
250
300
350
pnom mb

DRUCK TRANSDUCER
CERTIFICATION
ANALYSIS

Druck

CALIBRATION CERTIFICATE - RPT200S OPTION A

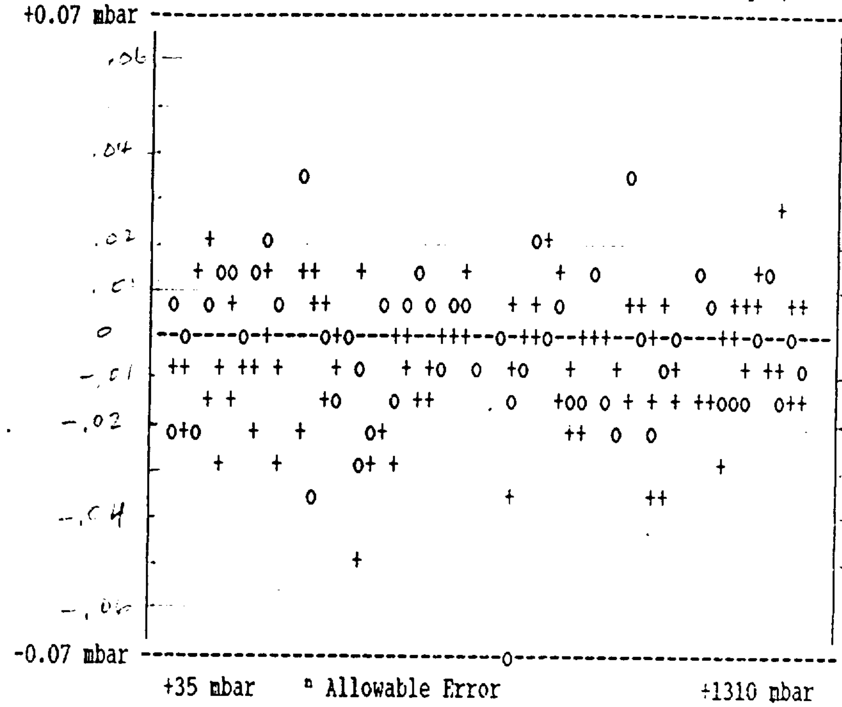
Serial Number: 1030406
Sensor serial number: ab/1/48
Date : 19/02/1998 Time :09:53:08
Calibrated pressure range 35 to 1310 mbar
temperature range -25 to +60 deg C

$$\text{Pressure} = \sum_{i=0}^{4} \sum_{j=0}^{3} K_{ij} * X'^{i} * Y'^{j}$$

Where (X'=frequency-X) and (Y'=diode voltage-Y)

K00: +6.4665674E+02	K01: -3.1055851E-02
K10: +4.0080243E-01	K11: -1.5821300E-06
K20: +1.8522480E-05	K21: +3.1184000E-10
K30: +4.9092702E-10	K31: -8.4519997E-14
K40: +3.7086999E-14	K41: -1.4432999E-16
K02: +5.3758002E-05	K03: -9.2995997E-08
K12: +4.1813002E-09	K13: -4.2222999E-11
K22: +2.8126999E-12	K23: -7.9703998E-14
K32: +2.2960001E-16	K33: +6.6150002E-18
K42: -7.0300002E-19	K43: +2.5263101E-20
X : +3.6172000E+04	Y : +5.3700000E+02
SN : 1030406	CS : +1.4782612E-96

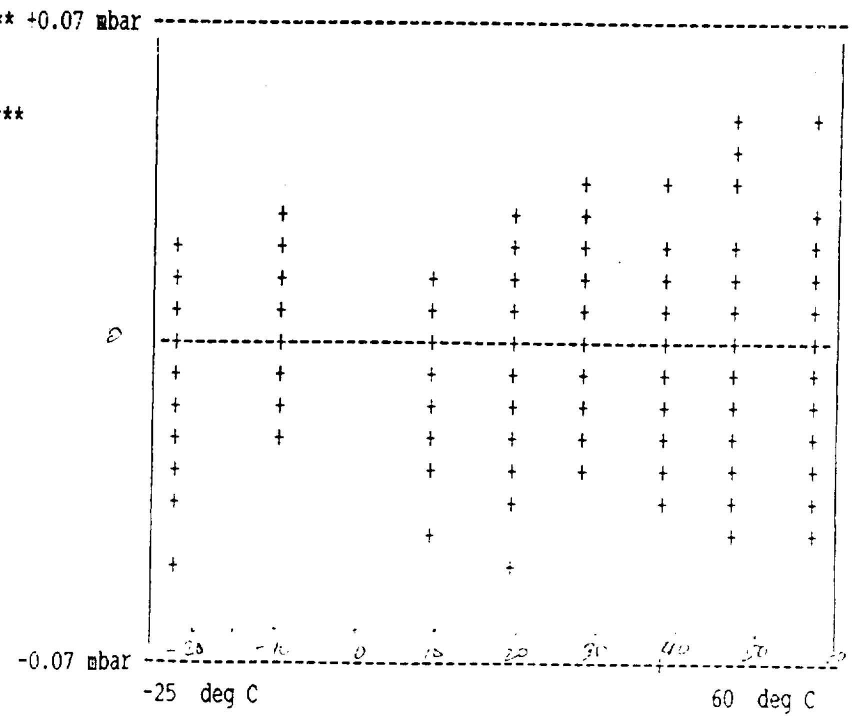
Residual errors against pressure
Key: Room temp + (+20 deg C) Worst temp o (+40 deg C)



mean dev = -.0044 mb
σ = ± .016 mb

Maximum error in all data is 0.069 mbar
Limit is 0.131 mbar *** PASS ***
Frequency at 1000 mbar / 20 deg C is 37020.441 Hz
Frequency range was 34517 to 37719 Hz
Average pressure sensitivity is +2.472 Hz/mbar
Limit is 1.70 to 3.50 Hz/mbar *** PASS **
Diode voltage range was +462 to +648 mV
Nominal diode sensitivity is -2.18 mV/deg C
Limit is -2.60 to -1.90 mV/deg C *** PASS ***

Residual errors against temperature



****
***** UNIT PASSED *****
****

PS266.exe Revision: 1.51
SMART Calibration Software Version 1.01
Limits taken from : \limits\p1791a.06b

I hereby certify that the
details above are correct -

[signature]

Druck

CALIBRATION CERTIFICAT. .T200S OPTION A

Serial Number: 1030406
Sensor serial number: ab/1/48
Date : 19/02/1998 Time :09:53:08
Calibrated pressure range 35 to 1310 mbar
temperature range -25 to +60 deg C

$$\text{Pressure} = \sum_{i=0}^{4} \sum_{j=0}^{3} K_{ij} \cdot X'^{i} \cdot Y'^{j}$$

Where (X'=frequency-X) and (Y'=diode voltage-Y)

K00: +6.4665674E+02	K01: -3.1055851E-02
K10: +4.0080243E-01	K11: -1.5821300E-06
K20: +1.8522480E-05	K21: +3.1184000E-10
K30: +4.9092702E-10	K31: -8.4519997E-14
K40: +3.7086999E-14	K41: -1.4432999E-16
K02: +5.3758002E-05	K03: -9.2995997E-08
K12: +4.1813002E-09	K13: -4.2222999E-11
K22: +2.8126999E-12	K23: -7.9703998E-14
K32: +2.2960001E-16	K33: +6.6150002E-18
K42: -7.0300002E-19	K43: +2.5263101E-20
X : +3.6172000E+04	Y : +5.3700000E+02
SN : 1030406	CS : +1.4782612E-96

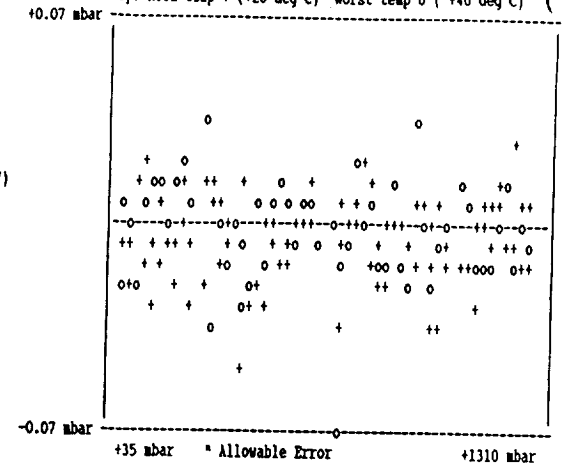
Maximum error in all data is 0.069 mbar
Limit is 0.131 mbar *** PASS ***
Frequency at 1000 mbar / 20 deg C is 37020.441 Hz
Frequency range was 34517 to 37719 Hz
Average pressure sensitivity is +2.472 Hz/mbar
Limit is 1.70 to 3.50 Hz/mbar *** PASS ***
Diode voltage range was +462 to +648 mV
Nominal diode sensitivity is -2.18 mV/deg C
Limit is -2.60 to -1.90 mV/deg C *** PASS ***

****
***** UNIT PASSED *****
****

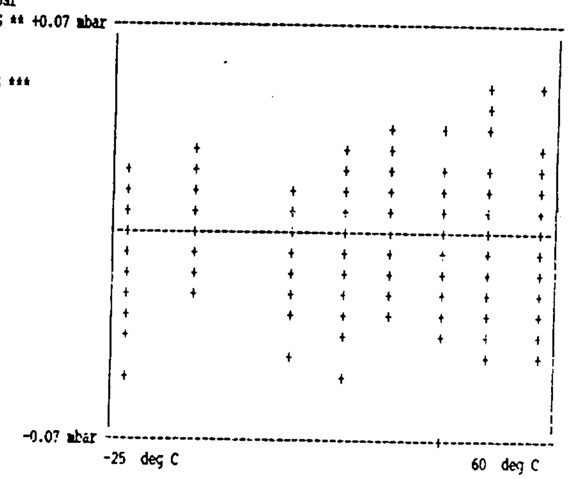
PS256.exe Revision: 1.51
SMART Calibration Software Version 1.01
Limits taken from : \limits\p1791a.06b

I hereby certify that the
details above are correct -

Residual errors against pressure
Key: Room temp + (+20 deg C) Worst temp o (+40 deg C)

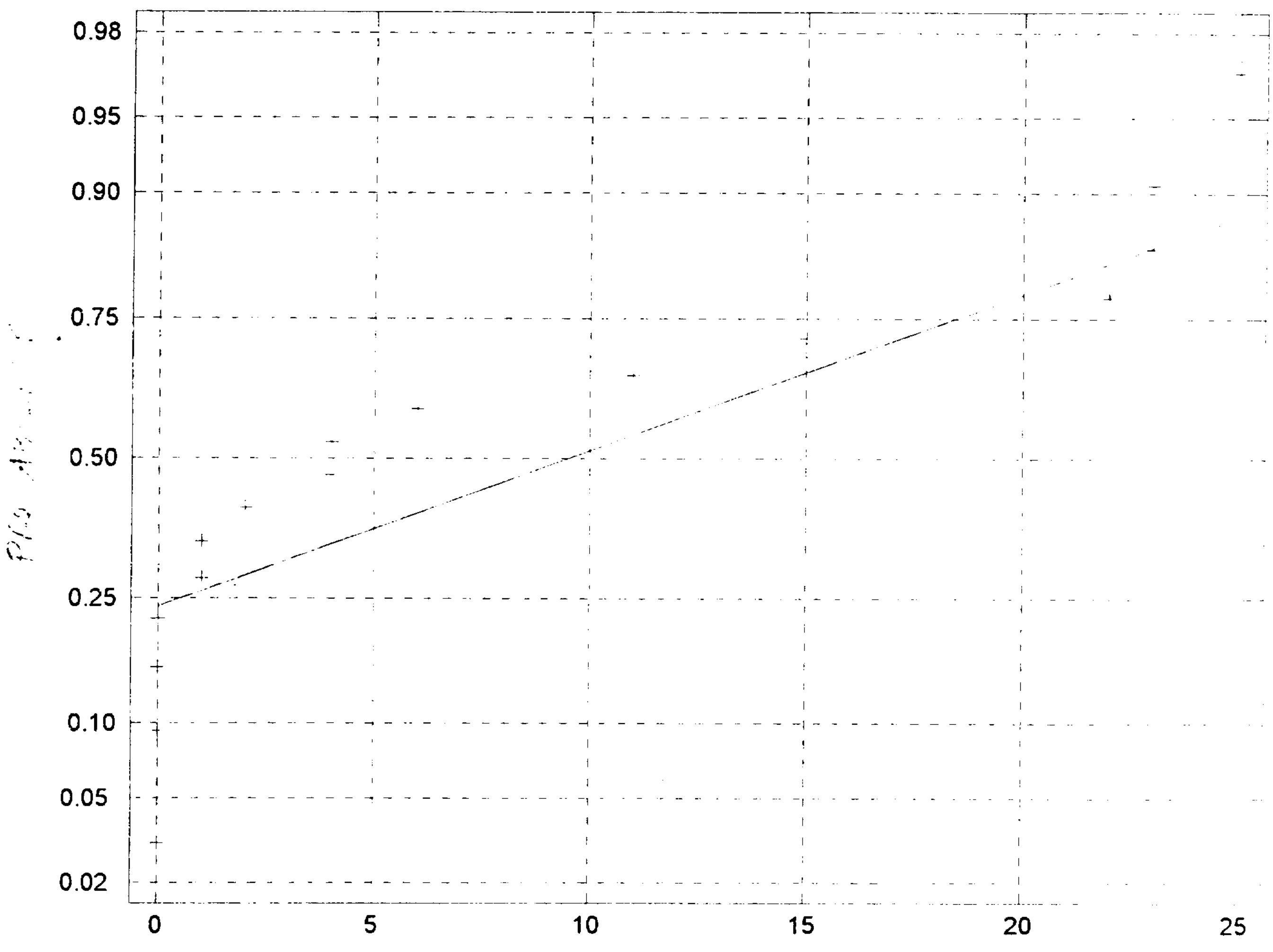


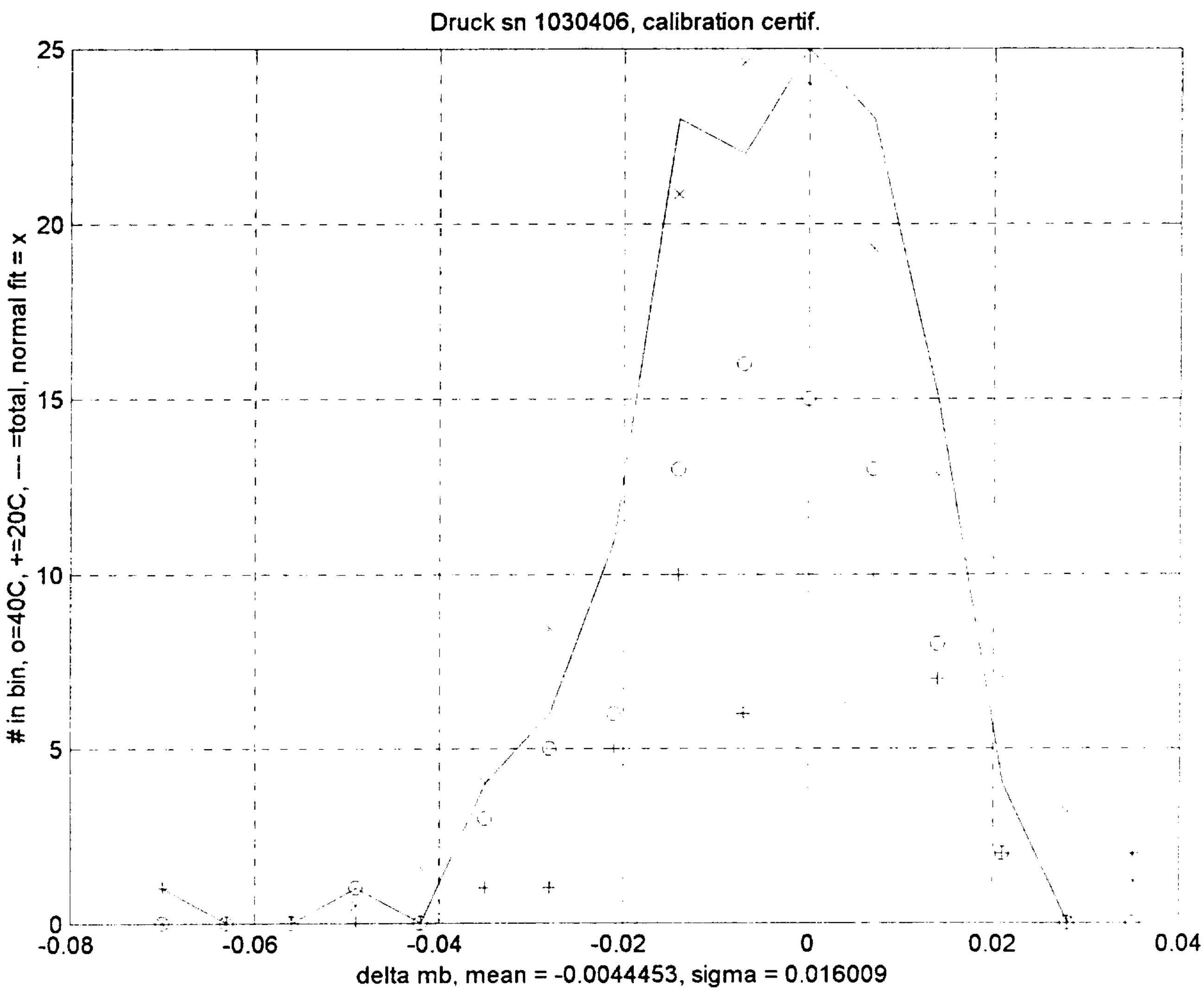
Residual errors against temperature



```
% druck sn 1030405 cal cetif data
% o=+40 C, + = + 20 C, nmbt = nmb40 C + nmb20 C
clear
x=.035:-.007:-.070;  %  x value
nbin=[2 0 4 15 23 25 22 23 11 6 4 0 1 0 0 1]; % total #, ie wt at x
nmb40=[2 0 2 7 10 10 6 10 5 1 1 0 0 0 0 1]; % number at 40 c
n=length(nbin);
nmb20=nbin-nmb40; % number at 20 C
cnmb=cumsum(nbin); % cumulative number in bins
xw=x.*nbin;  % bin x * number in bin
wsum=sum(nbin);  % total sum of wts
wtmean=sum(xw)/wsum % weighted mean
sigsq1=(sum(nbin.*((x-wtmean).^2))/wsum)*(n/(n-1)); % variance
sigma1=sqrt(sigsq1)
sigsq2=((sum(nbin.*x.^2)-wtmean^2*wsum)/wsum)*(n/(n-1));
sigma2=sqrt(sigsq2)

figure(1)
normplot(nbin)
pause

figure(2)
yy=normpdf(x,wtmean,sigma1);
plot(x,nmb40,'+',x,nmb20,'o',x,nbin,x,yy,'rx')
grid
title('Druck sn 1030406, calibration certif.')
xlabel(['delta mb, mean = ',num2str(wtmean),', sigma = ',...
      num2str(sigma1)])
ylabel('# in bin, o=40C, +=20C, --- =total, normal fit = x')
```

NORMAL PROBABILITY PLOT





Druck sn 1030406, calibration certif.
in bin, o=40C, +=20C, — =total, normal fit = x
25
20
15
10
5
0
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
delta mb, mean = -0.0044453, sigma = 0.016009

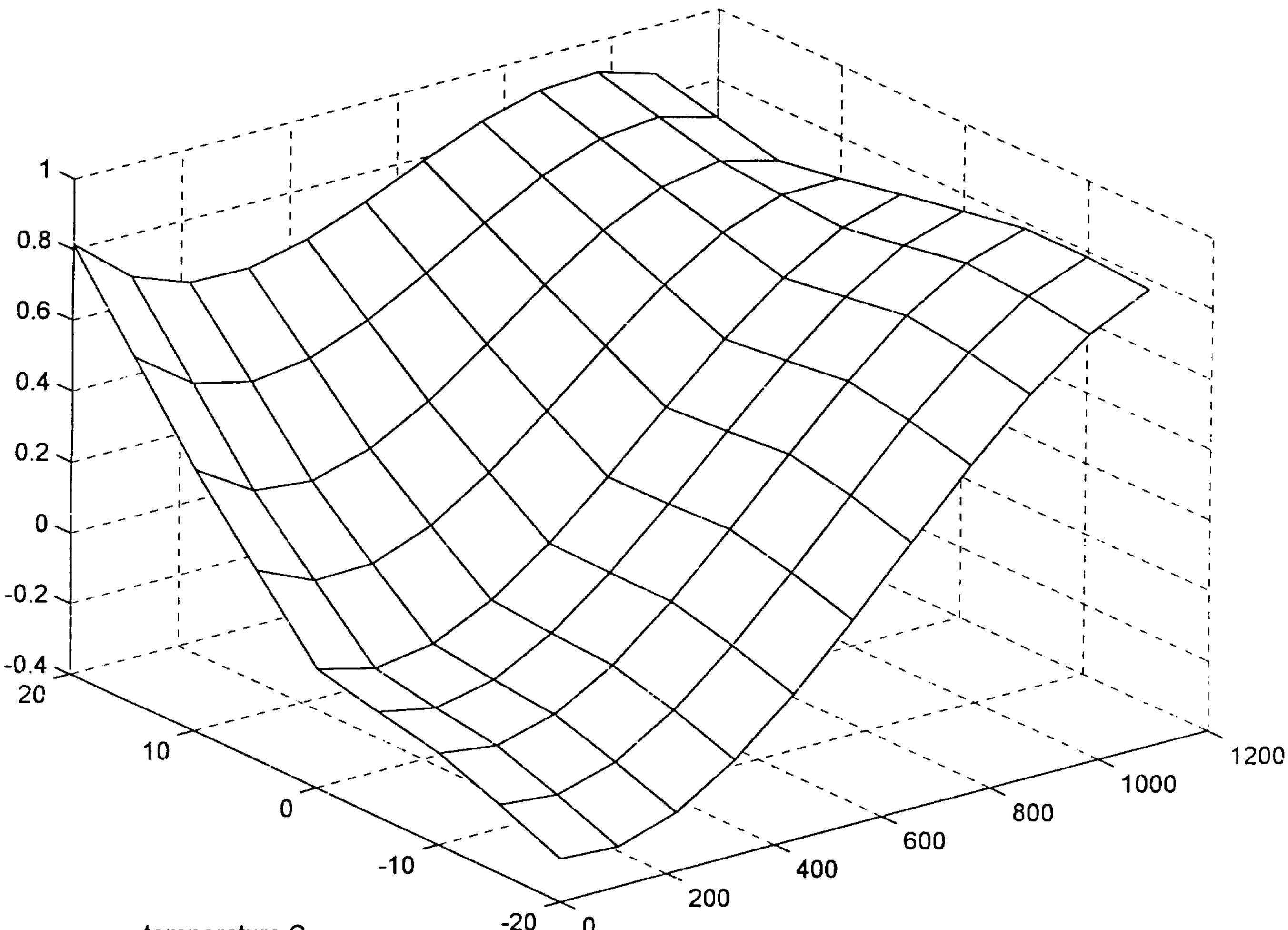
P_t SN 1613 SONEX

TEMPERATURE

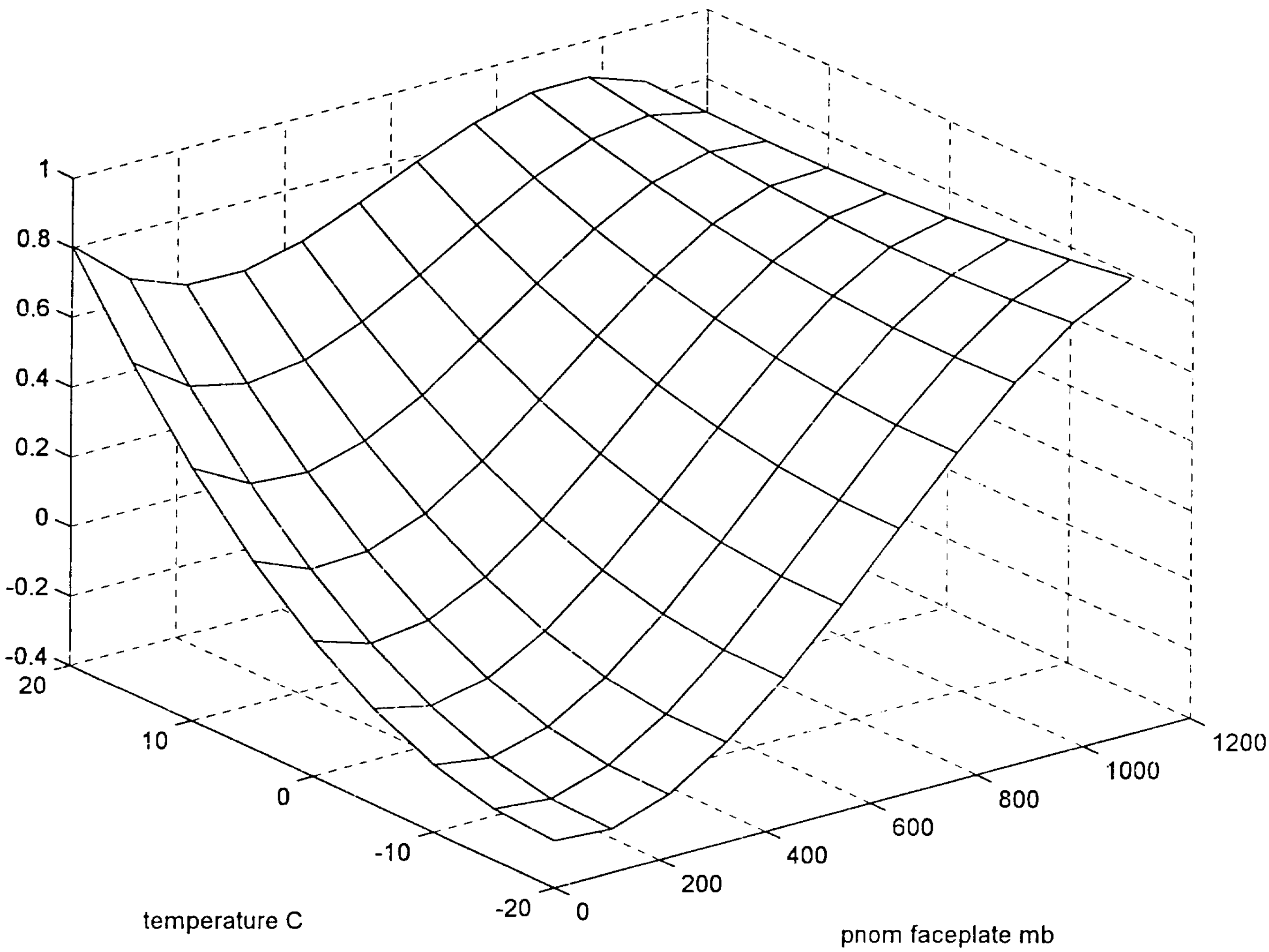
CALIBRATION

RESULTS

sn 1613 interpolated tfitted pvals(tcal)- faceplate



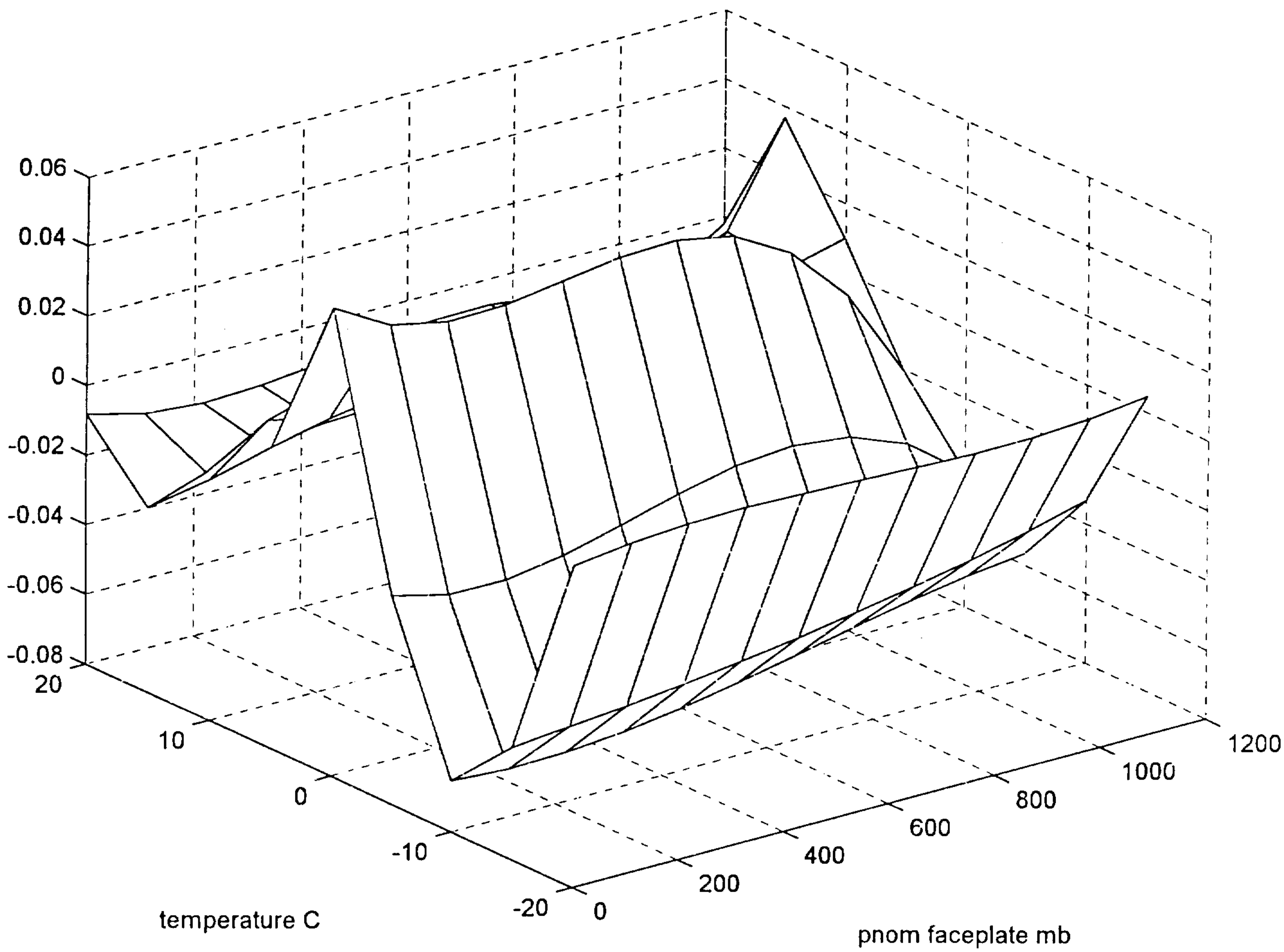
sn 1613 interpolated tfitted poly coeff - faceplate



COMPARISON OF FITTING 3rd ORDER POLYNOMIAL COEFFICIENTS AS FUNCTION OF TEMPERATURE

AND

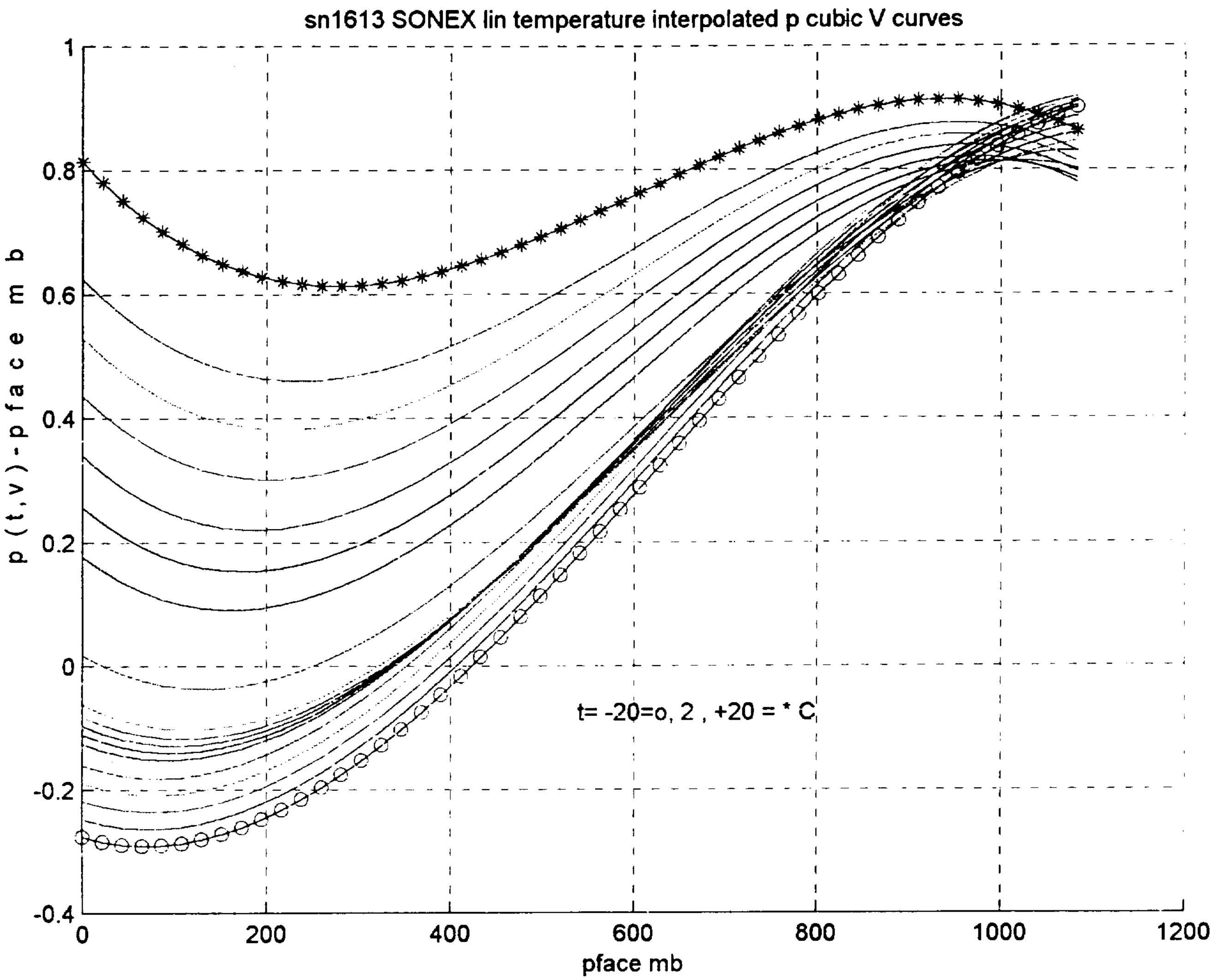
INTERPOLATING CUBIC CURVE FITS AT THE CALIBRATED TEMPERATURES sn 1613 tfit poly coeff - interpolated tfit pvals

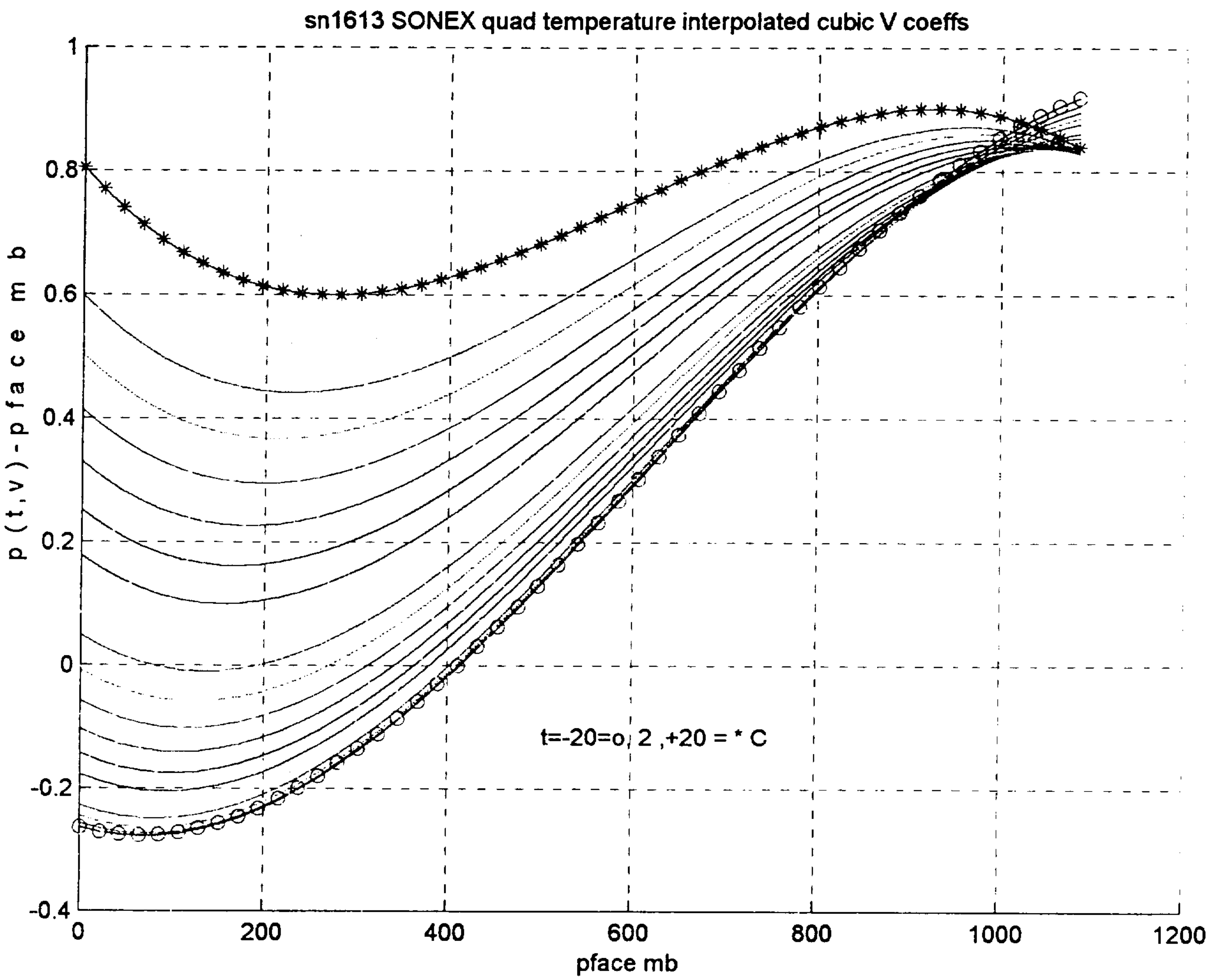


```
% s1613tt  comparision of coeff vs p temperature interpolation
%
% A format coeffs   a3 a2 a1 a0  in descending polyval order
%
% sn 1613 TC -20.90786  file pt_@m20
clear
  A(1,:) =[-1.7970705e-02  1.5603845e-01  2.1663572e+02 -2.9036691e-01 ];
  tcal(1)= -20.90786 ;
% sn 1613 TC -11.13017  file pt_@m10
  A(2,:) =[ -1.9856359e-02  1.6589020e-01  2.1660951e+02 -1.4852014e-01 ];
  tcal(2)= -11.13017 ;
% sn 1613 TC -.1640582  file pt_@0
  A(3,:) =[ -1.8952782e-02  1.6266842e-01  2.1657260e+02 -6.8682175e-02 ];
  tcal(3)= -.1640582;
% sn 1613 TC  9.469035  file pt_@10
  A(4,:) = [-2.5861053e-02  2.0674966e-01  2.1643361e+02  3.1533923e-01 ];
  tcal(4) = 9.469035;
% sn 1613 TC  20.24022  file pt_@20
  A(5,:) = [-2.1058185e-02  1.7712342e-01  2.1637759e+02  8.2516880e-01 ];
  tcal(5)= 20.24022;


   t=-20:5:20;  % C deg      t @ which to evaluate p
   v=0:.5:5;     % volt
   lt=length(t);lv=length(v);

 % fit p(v) at calibrated T 's
   for k=1:5
    % each row is the cubic poly fit in v  at tcal(k)
    % with the cols the values at each v
     pfitT(k,:)=polyval(A(k,:),v);
   end

% linear interpolate pfitT at each v using tcal vals in v col to t
% pfitTt will have lt rows and lv cols
   for k=1:1:lt
      for jv=1:1:lv
         Tpfit=pfitT(:,jv);
         pfitTt(k,jv)=interp1(tcal,Tpfit,t(k));
      end
   end

%  Now we try the other way
%  2nd order temperature fits of cubic p(v) polynom coeffs
     pcal=[-7.5447e-3,2.67471e-2,6.9535e-4;
          216.5444,-6.79603e-3,-1.03791e-4;
          .1790,7.7468e-4,-2.32399e-5;
         -.02165,-1.12863e-4,4.0308e-6]';
```

```
% 32 inch Hg = 5 v
faceplate=(32/(760/25.4))*(1013.25/5); %  32" /5v

tnom=20*ones(size(t));
[TNOM,V]=meshgrid(tnom,v);

% compute room =20 C  cubic coeffs for p(v)
a0n= pcal(1,1) + pcal(2,1)*TNOM + pcal(3,1)*TNOM.^2;
a1n= pcal(1,2) + pcal(2,2)*TNOM + pcal(3,2)*TNOM.^2;
a2n= pcal(1,3) + pcal(2,3)*TNOM + pcal(3,3)*TNOM.^2;
a3n= pcal(1,4) + pcal(2,4)*TNOM + pcal(3,4)*TNOM.^2;

% room temp values used in SUCCESS  file
%a0n=.81864207;
%a1n=216.38760;
%a2n=.15239554;
%a3n=-1.8510731e-2;

% cubic poly p, coeffs eval at 20 C
%pmb20 = a0n + a1n.*V + a2n.*V.^2 + a3n.*V.^3;


[T,V]=meshgrid(t,v);
%  compute using SONEX t fitted cubic p coeffs
a0t= pcal(1,1) + pcal(2,1)*T + pcal(3,1)*T.^2; % sonex
a1t= pcal(1,2) + pcal(2,2)*T + pcal(3,2)*T.^2;
a2t= pcal(1,3) + pcal(2,3)*T + pcal(3,3)*T.^2;
a3t= pcal(1,4) + pcal(2,4)*T + pcal(3,4)*T.^2;

pmbT = a0t + a1t.*V + a2t.*V.^2 + a3t.*V.^3;
pface=faceplate*V;pface=pface';
pmbT=pmbT';

figure(1)
atpnom=pfitTt-pface; % t fitted p values
mesh(faceplate*v,t,atpnom)
title('sn 1613 interpolated tfitted pvals(tcal)- faceplate')
xlabel('pnom faceplate mb ')
ylabel('temperature C')
pause

figure(2)
tapnom=pmbT-pface;  % t fitted poly coefs
mesh(faceplate*v,t,tapnom)
title('sn 1613 interpolated tfitted poly coeff - faceplate')
xlabel('pnom faceplate mb ')
```

```
ylabel('temperature C')
pause

figure(3)
mesh(faceplate*v,t,tapnom-atpnom)
title('sn 1613 tfit poly coeff - interpolated tfit pvals')
xlabel('pnom faceplate mb ')
ylabel('temperature C')
```


sn1613 SONEX lin temperature interpolated p cubic V curves
p (t , v) - p f a c e m b
pface mb
t= -20=o, 2 , +20 = * C
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
200
400
600
800
1000
1200



sn1613 SONEX quad temperature interpolated cubic V coeffs
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
200
400
600
800
1000
1200
p (t , v) - p f a c e m b
pface mb
t=-20=o, 2 ,+20 = * C

```
% sta1613.m  comparison of p(T) fits vs coeff(T) fits  sn 1613
clear
%  a0               a1               a2               a3               TC
pa=[ -2.903669E-01   2.166357E+02   1.560384E-01  -1.797071E-02  -2.090786E+01
     -1.485201E-01   2.166095E+02   1.658902E-01  -1.985636E-02  -1.113017E+01
     -6.868217E-02   2.165726E+02   1.626684E-01  -1.895278E-02  -1.640582E-01
      3.153392E-01   2.164336E+02   2.067497E-01  -2.586105E-02   9.469035E+00
      8.251688E-01   2.163776E+02   1.771234E-01  -2.105819E-02   2.024022E+01];

%   aai(T C)-->Ai to use in pmb = A0+A1*v+A2*v^2+A3*v^3

%  sn 1613coef a0  file \pdata\1613\t1613.cof
aa0 =[ -7.5447173e-03     4.69e-02
        2.6747140e-02     2.07e-03
        6.9535626e-04     1.70e-04];
%  sn 1613coef a1  file \pdata\1613\t1613.cof
aa1  = [ 2.1654442e+02     2.38e-02
        -6.7960295e-03     1.05e-03
        -1.0379082e-04     8.61e-05];
%  sn 1613coef a2  file \pdata\1613\t1613.cof
aa2 = [ 1.7900886e-01     1.44e-02
        7.7468427e-04     6.34e-04
       -2.3239906e-05     5.20e-05];
%  sn 1613coef a3  file \pdata\1613\t1613.cof
aa3 =[ -2.1650919e-02     2.27e-03
       -1.1286328e-04     1.00e-04
        4.0307988e-06     8.21e-06];

t=-20:2:20;lt =length(t);
v=0:.1:5;lv=length(v);
Tpcal =pa(:,5);
faceplate=(32/(760/25.4))*(1013.25/5);  % 32" Hg = 5v
pface=faceplate*v;


%  compute poly t dependent coeffs
aa0=aa0';aa0=fliplr(aa0);a0t=polyval(aa0(1,:),t);
aa1=aa1';aa1=fliplr(aa1);a1t=polyval(aa1(1,:),t);
aa2=aa2';aa2=fliplr(aa2);a2t=polyval(aa2(1,:),t);
aa3=aa3';aa3=fliplr(aa3);a3t=polyval(aa3(1,:),t);

aat=[a3t' a2t' a1t' a0t']';

% values from temperature interpolated coeffs aat
for ir=1:lt
    pat(ir,:)=polyval(aat(:,ir),v);
end

for ir=1:lt
   pfacem(ir,:)=ones(size(pface)).*pface;
end
figure(1)
hold
plot(pface,pat-pfacem)
plot(pface,pat(1,:)-pface,'o')
plot(pface,pat(lt,:)-pface,'*')

xlabel('pface mb'),ylabel('p(t,v)-pface mb')
title('sn1613 SONEX quad temperature interpolated cubic V coeffs')
grid
gtext('t= -20=o, 2 , +20 = * C')
hold off

% now linearly interpolate the p values at Tpcal
% put into polyval order
pc=[pa(:,4) pa(:,3) pa(:,2) pa(:,1)];
```

```
for ir=1:5
   pcalT(ir,:)=polyval(pc(ir,:),v);
end
for k=1:lt  % each row is cubic ploy fits at each Tpfit
   for jv=1:lv
      Tpfit=pcalT(:,jv);
      pfitTt(k,jv)=interp1(Tpcal,Tpfit,t(k));
   end
 end
 figure(2)
 hold
plot(pface,pfitTt-pfacem)
plot(pface,pfitTt(1,:)-pface,'o')
plot(pface,pfitTt(lt,:)-pface,'*')

xlabel('pface mb'),ylabel('p(t,v)-pface mb')
title('sn1613 SONEX lin temperature interpolated p cubic V curves')
grid
gtext('t= -20=o, 2 , +20 = * C')
hold off
```

```
» whos
  Name              Size              Bytes  Class

  Tpcal             5x1                  40  double array
  Tpfit             5x1                  40  double array
  a0t               1x21                168  double array
  a1t               1x21                168  double array
  a2t               1x21                168  double array
  a3t               1x21                168  double array
  aa0               2x3                  48  double array
  aa1               2x3                  48  double array
  aa2               2x3                  48  double array
  aa3               2x3                  48  double array
  aat               4x21                672  double array
  faceplate         1x1                   8  double array
  ir                1x1                   8  double array
  jv                1x1                   8  double array
  k                 1x1                   8  double array
  lt                1x1                   8  double array
  lv                1x1                   8  double array
  pa                5x5                 200  double array
  pat              21x51               8568  double array
  pc                5x4                 160  double array
  pcalT             5x51               2040  double array
  pface             1x51                408  double array
  pfacem           21x51               8568  double array
  pfitTt           21x51               8568  double array
  t                 1x21                168  double array
  v                 1x51                408  double array

Grand total is 3844 elements using 30752 bytes

»
```

```
» whos
  Name               Size          Bytes  Class

  Tpcal              5x1              40  double array
  Tpfit              5x1              40  double array
  a0t                1x21            168  double array
  a1t                1x21            168  double array
  a2t                1x21            168  double array
  a3t                1x21            168  double array
  aa0                2x3              48  double array
  aa1                2x3              48  double array
  aa2                2x3              48  double array
  aa3                2x3              48  double array
  aat                4x21            672  double array
  faceplate          1x1               8  double array
  ir                 1x1               8  double array
  jv                 1x1               8  double array
  k                  1x1               8  double array
  lt                 1x1               8  double array
  lv                 1x1               8  double array
  pa                 5x5             200  double array
  pat               21x51           8568  double array
  pc                 5x4             160  double array
  pcalT              5x51           2040  double array
  pface              1x51            408  double array
  pfacem            21x51           8568  double array
  pfitTt            21x51           8568  double array
  t                  1x21            168  double array
  v                  1x51            408  double array

Grand total is 3844 elements using 30752 bytes

» p20=polyval(pc(5,:),v);
» plot(pface,p20-pface
??? lot(pface,p20-pface
                        |
Improper function reference. A "," or ")" is expected.

» plot(pface,p20-pface)
» title('sn 1613 using TC= 20.24022 cubic coeffs')
» xlabel(pface  mb'),ylabel('p(v, T=20.24022) - pface  mb')
??? xlabel(pface  mb
                  |
Improper function reference. A "," or ")" is expected.

» xlabel('pface  mb'),ylabel('p(v, T=20.24022) - pface  mb')
» grid
» print -dwinc
» aat
```

lt = 21
lv = 51

aat =

Columns 1 through 7

-0.0178	-0.0183	-0.0188	-0.0193	-0.0197	-0.0201	-0.0205
0.1542	0.1575	0.1607	0.1636	0.1664	0.1689	0.1713
216.6388	216.6331	216.6266	216.6192	216.6110	216.6020	216.5921
-0.2643	-0.2637	-0.2575	-0.2457	-0.2284	-0.2055	-0.1770

Columns 8 through 14

-0.0208	-0.0211	-0.0214	-0.0217	-0.0219	-0.0220	-0.0222
0.1735	0.1755	0.1774	0.1790	0.1805	0.1817	0.1828
216.5815	216.5699	216.5576	216.5444	216.5304	216.5156	216.4999
-0.1430	-0.1034	-0.0583	-0.0075	0.0487	0.1106	0.1780

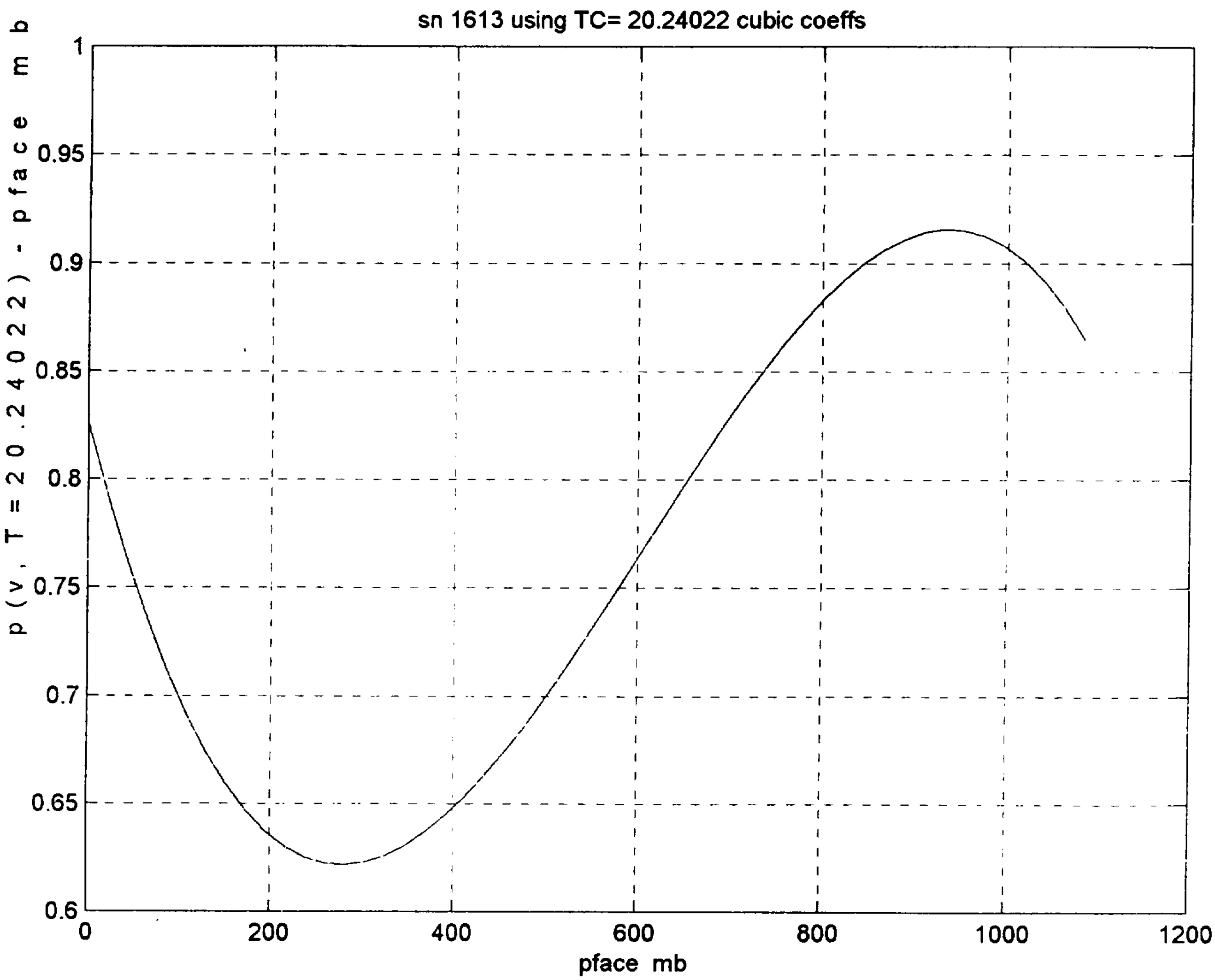
Columns 15 through 21

-0.0223	-0.0224	-0.0224	-0.0224	-0.0224	-0.0224	-0.0223
0.1837	0.1844	0.1850	0.1853	0.1855	0.1854	0.1852
216.4834	216.4661	216.4479	216.4289	216.4091	216.3885	216.3670
0.2509	0.3295	0.4136	0.5032	0.5984	0.6992	0.8055

»

CUBIC V COEFFICENTS DERIVED
FROM 2nd ORDER T(-20,2,20) FITS
OF CALIBRATED T FIT COEFFICIENTS

```
» pc

pc =

   -0.0180    0.1560  216.6357   -0.2904
   -0.0199    0.1659  216.6095   -0.1485
   -0.0190    0.1627  216.5726   -0.0687
   -0.0259    0.2067  216.4336    0.3153
   -0.0211    0.1771  216.3776    0.8252

» Tpcal

Tpcal =

  -20.9079
  -11.1302
   -0.1641
    9.4690
   20.2402

»
```


sn 1613 using TC= 20.24022 cubic coeffs
p(v, T=20.24022) - pface mb
pface mb
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0
200
400
600
800
1000
1200