DOE/CE/15517--T2

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1st Quarter 1992
Technical Progress Report

for

Instrumentation of Dynamic Gas Pulse Loading System

Grant Number DE-FG01-91CE15517
Grant Duration 9/19/91 - 3/18/93

submitted to:

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on

April 14, 1992

by

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Approved by H. J. Mohaupt Date 4/14/92

Project Description (Attachment A)

The overall goal of this work is to further develop and field test a system of stimulating oil and gas wells, which increases the effective radius of the well bore so that more oil can flow into it, by recording pressure during the gas generation phase in real time so that fractures can be induced more predictably in the producing formation.

Task 1. Complete the laboratory studies currently underway with the prototype model of the instrumentation currently being studied.
Task 2. Perform field tests of the model in the Taft/Bakersfield area, utilizing operations closest to the engineers working on the project, and optimize the unit for various conditions encountered there.
Task 3. Perform field test of the model in DGPL jobs which are scheduled in the mid-continent area, and optimize the unit for downhole conditions encountered there.
Task 4. Analyze and summarize the results achieved during the complete test series, documenting the steps for usage of downhole instrumentation in the field. and compile data specifying use of the technology by others.
Task 5. Prepare final report for DOE, and include also a report on the field tests completed. Describe and estimate the probability of the technology being commercialized and in what time span.

Summary

The project has made substantial technical progress, though we are running about a month behind schedule. Expenditures are in line with the schedule. Increased widespread interest in the use of DGPL stimulation has kept us very busy. The computer modeling and test instrumentation developed under this program is already being applied to commercial operations.

Technical Activities Overview for January 1 to March 31, 1992:

Task 1. Laboratory studies and analysis:

A. Laboratory closed chamber tests of ignitor material.
B. Three simultaneous channels of 20 KHz sampling demonstrated with the RTD A/D board. Exchange for an improved version of the board is under way.
C. A quantitative computer model for the DGPL process is being used in planning commercial DGPL stimulation.

Task 2. Field tests at the Servo-Dynamics Maricopa test site in the Taft-Bakersfield area:

A. A 3000 psi test chamber based on N-80 2-7/8" tubing has been designed and assembled.
B. An electrical ignition system has been developed and tested.
C. Site preparation is underway.
D. A critical experiment is planned to evaluate peak pressure generation using a modified tool designed for CO_2 injection wells in Texas.

Task 3. Downhole tests of computer models in commercial DGPL jobs:

A. Initial design of an electronic battery-operated downhole recorder system has begun.
B. Parts for a prototype downhole recorder system have been purchased.
C. Selection of suitable areas for field studies is underway.

Technical Discussion

Task 1. A. Laboratory Studies

The standard STRESSFRAC™ tool used for Dynamic Gas Pulse Loading™ (DGPL™) is a two stage gas generator, with an interior ignitor core in 1/4 inch aluminum tubing surrounded by slow Type CT propellant. The ignitor not only heats the propellant, but also rapidly develops a relatively high pressure which mechanically alters the propellant and establishes the initial reaction pressure for the larger propellant mass. A short series of tests was carried out to measure the pressure generated by a small quantity of ignitor in a closed chamber with a known relief volume. Measured pressure-time data is shown in figures 1,2 and 3. Strong pressure oscillations are observed which appear to correspond to the breathing mode of the steel chamber. A piston with copper shear pin was used to protect against over-pressure. The first two shots of 5 and 7.5 grains did not cut the shear pin, although the second shot came close. The third shot, with a full 10 grain charge, cut the shear pin and relieved the pressure. Surprisingly, the PCB transducer shows that higher peak pressure of 8000 psi was achieved on the 7.5 grain shot than on the third 10 grain shot which reached 6000 psi. Examination of the aluminum tubing holding the charge showed evidence of increasingly violent rupture. The pressure rise during the first 0.1 millisecond is more in line with the quantity of material than the peak pressure: 800 psi for 5 gr, 1800 psi for 7.5 gr, and 6000 psi for 10 gr. The surprising low peak pressure on the third shot is probably due to expansion of the chamber volume as the shear pin was cut in the pressure relief piston. The very strong pressure oscillations in this small chamber tend to obscure the pressure increase caused by the gas generation rate. Similar experiments will be carried out in the larger Maricopa test chamber where burn rate can be more clearly distinguished from the chamber resonances.

Task 1. B. Improved Recorder Speed

The new Real Time Devices ADA3100 A/D board was installed in the 486-33 computer and our original software was substantially re-written for this board and the high resolution color display of the computer. The board is rated at 200 KHz sampling rate and we were able to operate at 166 KHz with a compiled QuickBasic polling routine. Typical data obtained with this new system is shown in the figures. The original board can operate at 166 KHz on a single channel, or automatically multiplex through all 8 channels at 166 KHz, providing an approximately 20 KHz sampling rate on each channel. Some of the transient pressure waves in the cascade pressure test fixture seem to be at about 10 KHz, so it would be very useful to push the multichannel rate up above 20 KHz. This can be achieved with a very recent revision of the RTD ADA3100 which allows the automatic addressing mode to cycle over a smaller number of addresses, so that we could operate at 80 KHz with two channels or 40 KHz with 4 channels. RTD has offered to exchange our boards for the newer model for a nominal handling fee, and this exchange is now in progress.

Task 1C Equilibrium Volume Computer Model

A computerized equilibrium model has been developed to estimate the maximum extent of fractures produced by the DGPL pressurization with StressFrac tools of various lengths and diameters. The equilibrium volume model is based on the ideal gas law for the combustion products, which are primarily carbon dioxide and carbon monoxide. The model assumes that the formation will fracture and that the closure pressure will correspond to the known hydraulic fracture gradient for the formation. The gas volume is divided into three parts: the original tool volume, the casing volume opened by compression of the fluid in the casing, and the fracture volume. This model has been put into routine use in planning DGPL stimulations and some useful insight into the process has already resulted. The source code of the model is given in appendix.

The computer model parameters such as average fracture width, gas generation rate, and heat retention have been adjusted to give agreement with the limited data now available. The A useful guide is provided by the Sandia mine-back experiments described in "Multi-Frac Test Series Final Report", SAND81-1239, by R.A. Schmidt, N.R. Warpinski, et. al., 1981. Another remarkable case was the use of 35,000 pounds of propellant in a 1970 series of experiments which opened a channel to two other wells in separate quadrants, each 2,000 feet away. As described in World Oil of November 1970, a fracture radius of 600 feet was estimated from the large increase in gas production. That massive stimulation was contained in a 10 foot thick zone by impervious rock above and below. The 35,000 pounds of propellant corresponds to an 80 inch diameter tool, 10 feet high. When the end effect fracture parameter in the model was reduced to .03 to contain the fractures in the ten foot zone, the computer model predicted four wing 2 mm wide fractures of 1,325 foot radius, in qualitative agreement with experience.

The fluid compression is calculated from simple one dimensional momentum conservation for a fluid with known density and sound speed. This results in a column of fluid moving away from the gas generator with a velocity proportional to the pressure difference between the hydrostatic pressure and the closure pressure. A typical velocity is 10 meters/sec, and for a 12 foot long, 2 inch diameter tool the gas is generated in about 0.15 seconds so the fluid column moves about 1.5 meters during the process. The gas volume remaining in the wellbore is equal to the wellbore area times the 1.5 meter fluid motion (or 3 meters if the fluid compresses below the tool as well as above it). In shallow wells the wellbore volume is a small fraction of the total gas volume, but in deep wells the high pressure reduces the gas volume and the wellbore fraction becomes quite important. The wellbore volume resulting from fluid compression provides an important safety valve for the DGPL process, limiting the peak pressure to safe values even when the formation fails to fracture. This should be contrasted with the use of high explosives or even Primacord, which generate very high pressures since the well fluid does not have time to compress and move out of the way. The model calculations provide a useful guide in unfamiliar situations, suggesting the use of packers to contain the fluid in DGPL treatment of deep large diameter wells.

An example of the equilibrium model predictions is shown in figure 4 for a typical well of Arco Alaska in Prudhoe Bay. Four similar wells were stimulated with STRESSFRAC tools to prepare them for hydraulic mud acid mud treatment. The preliminary localized DGPL treatment was used to protect the integrity of nearby cement squeeze perforations that might be inadvertently opened by the mud acid treatment. Two successive STRESSFRAC stimulations were made in each of the four wells. Two wells showed a substantial improvement in injectivity, one well showed slight improvement, and one well showed no improvement at all. The project engineer concluded that STRESSFRAC stimulation provided a viable alternative to ballouts for the production of localized fractures to increase injectivity for those cases where ballouts were not effective.

Arco's fracture gradient data implied a closure pressure of about 5600 psi. In both of the successful wells, the second DGPL stimulation reached a peak pressure of 6000 psi as measured by the Servo-Dynamics passive peak pressure gage. The first stimulations in these wells reached 6700 and 8800 psi respectively. The well that showed slight improvement dropped from 9400 psi to 6900 psi on the second stimulation. The well that showed no improvement actually increased from 8500 to 9800 psi on the second stimulation.

Several conclusions can be drawn from this peak pressure data:

1. DGPL fracture generation occurs at pressures slightly above the hydraulic fracture gradient, as expected.

2. The time history of the pressure provides useful information about the development of fractures. On both successful wells the pressure dropped nearly to the hydraulic closure pressure on the second stimulation. We hope to see this occur during a single shot by measuring the pressure-time history.

3. When no fractures are formed and the gas remains in the wellbore, the compression of the fluid column limits the peak pressure to a safe value.

4. In deep wells where the gas volume is small, it may be desirable to improve gas injection efficiency by reducing the wellbore area with solid tubing or using flow restricting packers. The Servo-Dynamics Equilibrium model predicted that about 30% of the gas volume would remain in the wellbore on these stimulations.

Task 2. A. Test Chamber A 3000 psi test chamber based on N-80 2-7/8" tubing has been designed and assembled for use in field tests at the Servo-Dynamics Maricopa test site in the Taft-Bakersfield area. This tubing is rated at 10,000 psi burst pressure. Fittings of 3000 psi forged steel pipe have been welded onto the tubing to allow convenient access for pressure sensors and relief ports. The test chamber will be used for tests of ignition material as well as Servo-Dynamics CT propellant tools. The test chamber is assembled from standard N-80 oil field tubing to allow various configurations of propellant, sensors, and relief ports. Studies will be directed toward measurement of peak closed chamber pressures and gas generation rates. The influence of pressure on burn rate is of particular interest.

Task 2. B. Test Ignition An electrical ignition system has been developed and tested. This system will employ a bull plug with electrical feedthrough previously developed for downhole use. The ignition configuration for ignitor tests has been tested in the laboratory chamber.

Task 2. C. Field Test Site The Maricopa field test site has not been available during the last two months because of unusually frequent rain. At this time a large stand of weeds has grown up which will be mowed to reduce fire danger. Site preparation is should be completed by mid April.

Task 2. D. Ignitor Tests Shell Oil has an requirement for restoring the injection profile in a number of CO_2 injection wells in Texas. These wells provide very limited access diameter, and the standard STRESSFRAC tools can not be used. The standard 1/4 inch ignition assembly does not provide enough gas volume for the application. To solve this problem, an experimental ignitor has been designed using 3/8 inch tubing. Pressure measurements will be made comparing a short length of this new design to the standard 1/4 inch design to determine the operating pressure range of the new device. Test samples are now being prepared. These tests will be the first use of the new Maricopa test facility and test chamber.

Task 3. Downhole test plans Downhole tests in commercial DGPL jobs present a variety of technical problems. No single instrumentation system seems adequate for the whole range of situations. Our laboratory apparatus, with 486-33 computer, 110 v generator, and electrical sensors, can only be used with wireline jobs at a limited depth and limited temperature. This approach provides the most direct extension of our lab work but it can not always be used in practice.

Task 3. A. Downhole Recorder In order make pressure recordings on tubing conveyed stimulations, the recorder must ride down with the tool. Initial design parameters of an electronic battery operated downhole recorder system have been defined. Parts for a prototype downhole recorder system have been purchased. A microcomputer board less than two inches wide that can be programmed from an RS-232 serial cable has been purchased. This board provides a real time clock, low power sleep state and 32 K Bytes of RAM memory. An Analog Devices AD7828 multiplexing 8 bit flash converter will be used to digitize the signals. This prototype system will be limited to operation below 70 °C or 158 °F. Even with the best military grade parts this approach is limited to 125°C or 257°F.

Task 3. B. Other Instrumentation Considerable thought has gone into the use of more comprehensive non-electronic gages, or of seismic detection at the surface. A simple form of seismic sensing may be developed to provide information about the number of major fractures initiated in stimulations by 1000 foot long STRESSFRAC tools now used for completion of horizontal wells.

Task 3. C. Downhole Test Site Selection Selection of suitable areas for field studies is underway. Major segments of the US oil industry are adapting to a switch to enhanced oil recovery methods in the continental US. Very few new wells are being drilled. A major problem in US oil fields is to economically maintain production in wells that are 30 or even 60 years old. Many of our customers are interested in restoring lost permeability in wells that have been clogged by the migration of fine sands, asphaltines and other particulates, or sealed off by inappropriate chemical treatment. Other producers are concerned with maintaining injectivity in steam floods, water re-use, and CO_2 injection wells. Slotted liners that have been plugged by sand and scale must be cleaned or removed. All of these applications require the accurately placed fractures than can be produced with DGPL. These wells respond very well to the creation of new fractures of 1 to 20 foot radius around the wellbore.

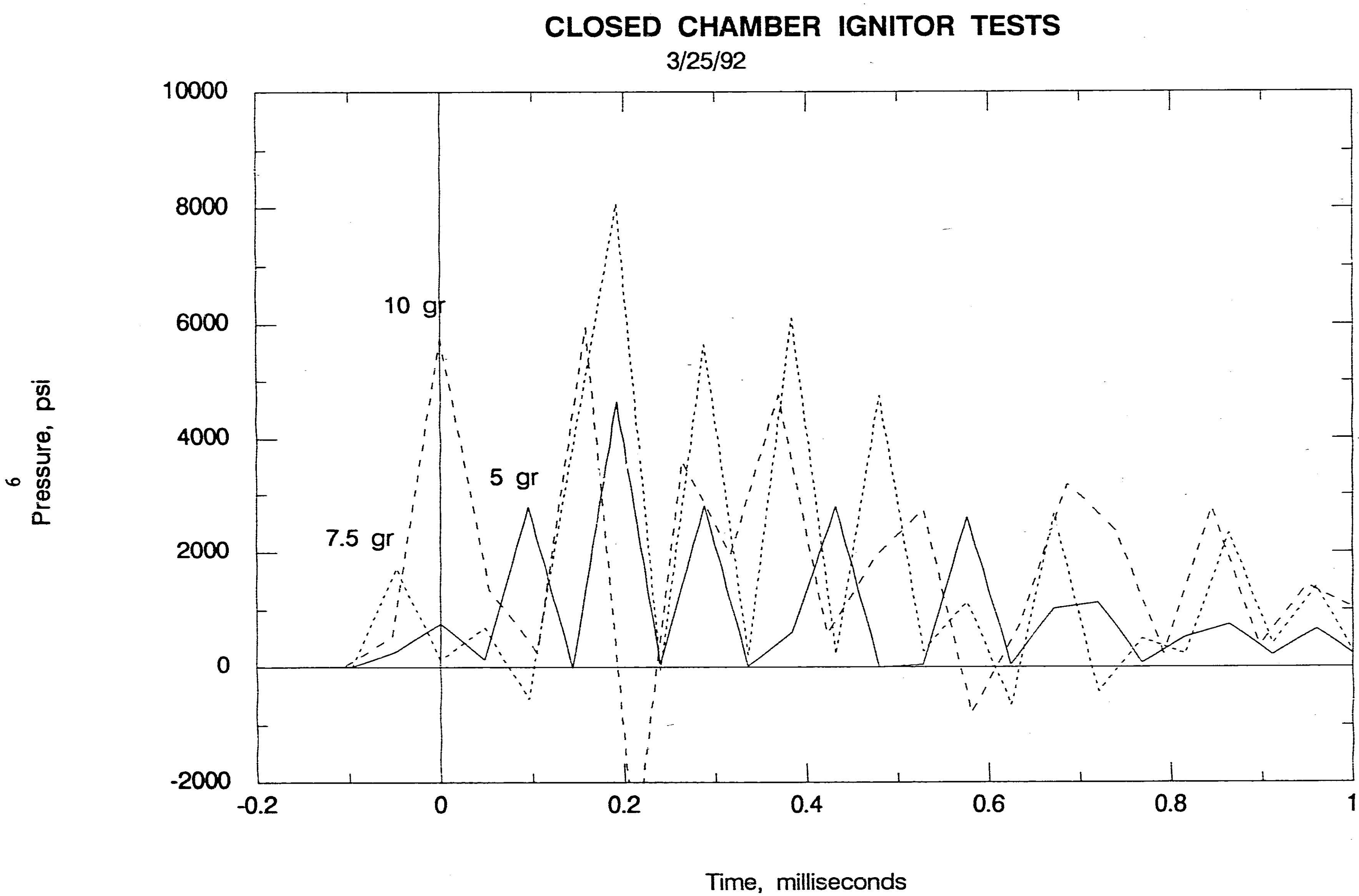
California:
The Subscales formation of the Elk Hills Naval Oil Reserve operated by Bechtel is one of the more promising locations for field testing. Cleaning, recompletion or removal of old slotted liners of hundreds of wells in this area can be accomplished with DGPL. Recent tests have shown dramatic production increases after STRESSFRAC stimulation of older production wells. One well went from 8 bopd to its original production level of 45 bopd after STRESSFRAC stimulation, while a twin test well dropped from 8 bopd to 4 bopd after extensive acid treatment. The Elk Hills wells are 2500 to 3000 feet deep and typically 160°F. Tubing conveyed STRESSFRAC tools are commonly used, though occasional opportunities arise for wire line pressure measurements. The injector wells are usually under pressure, and stimulated using a wire line tool introduced through a lubricator. Operating temperature in injector wells is usually too high for the pressure sensor. Santa Fe Energy, Mobile, and Chevron have similar requirements in this area.

Texas:
Shell found that 2 of 3 fifty year old wells doubled their production after DGPL stimulation. These wells are 5000 ft deep and 180°F, and so they present greater instrumentation problems than the wells available in California. Shell also has several hundred water and CO_2 injection wells that require DGPL stimulation to improve injectivity. There is a 1000 ft long horizontal STRESSFRAC stimulation planned at 6600 feet in the Austin Chalk formation by another producer. This stimulation presents an unusual instrumentation challenge, and seismic recording may provide the most useful measure of the timing, location and direction of the fractures.

Colorado, North Dakota, Kansas, Kentucky, Pennsylvania, Aberdeen Scotland:
A variety of stimulations are being planned which may present opportunities for instrumentation tests. These include completion of a new oil well, repair of a well plugged by heavy muds, recompletion of a gas well, management of water problems in an oil well, etc. Formation breakdown and scale control stimulations in geothermal wells in California and Nevada will require operation at 300 to 380°F.

Budget Summary

		Cumulative Cost, $	
		Plan	Actual
Lab Studies	Oct 91	11,560	
	Nov	15,974	
California Studies	Dec	28,393	20,774
	Jan 92	38,197	
US Studies	Feb	43,731	
	Mar	48,390	42,572
	Apr	53,624	
	May	59,108	
	Jun	63,517	
	Jul	69,351	
Final Report	Aug	78,868	
	Sep	88,335	



CLOSED CHAMBER IGNITOR TESTS
3/25/92
10000
8000
6000
4000
2000
0
-2000
Pressure, psi
10 gr
5 gr
7.5 gr
-0.2
0
0.2
0.4
0.6
0.8
1
Time, milliseconds

Figure 1

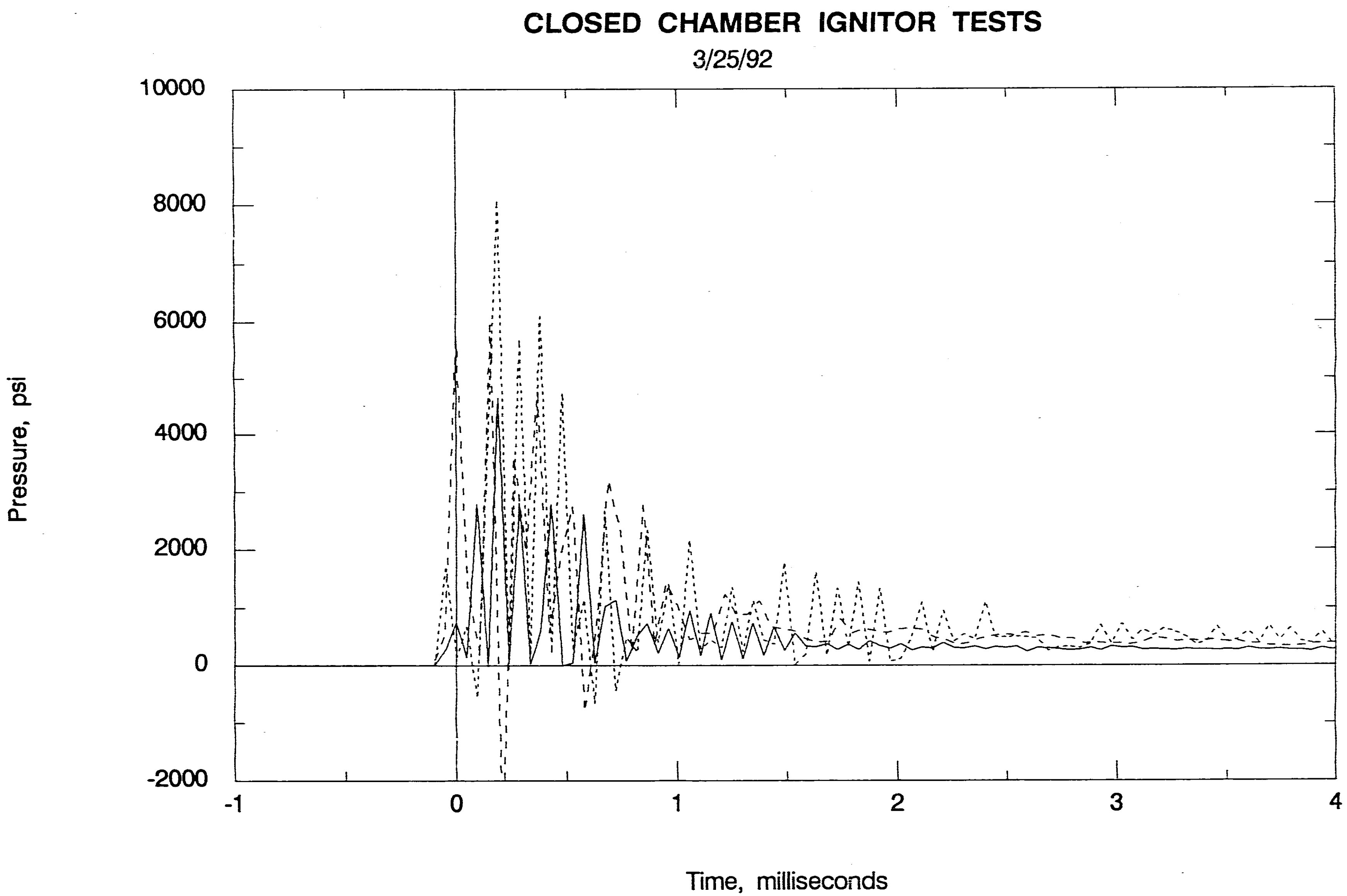

CLOSED CHAMBER IGNITOR TESTS
3/25/92
10000
8000
6000
4000
2000
0
-2000
Pressure, psi
-1
0
1
2
3
4
Time, milliseconds

Figure 2

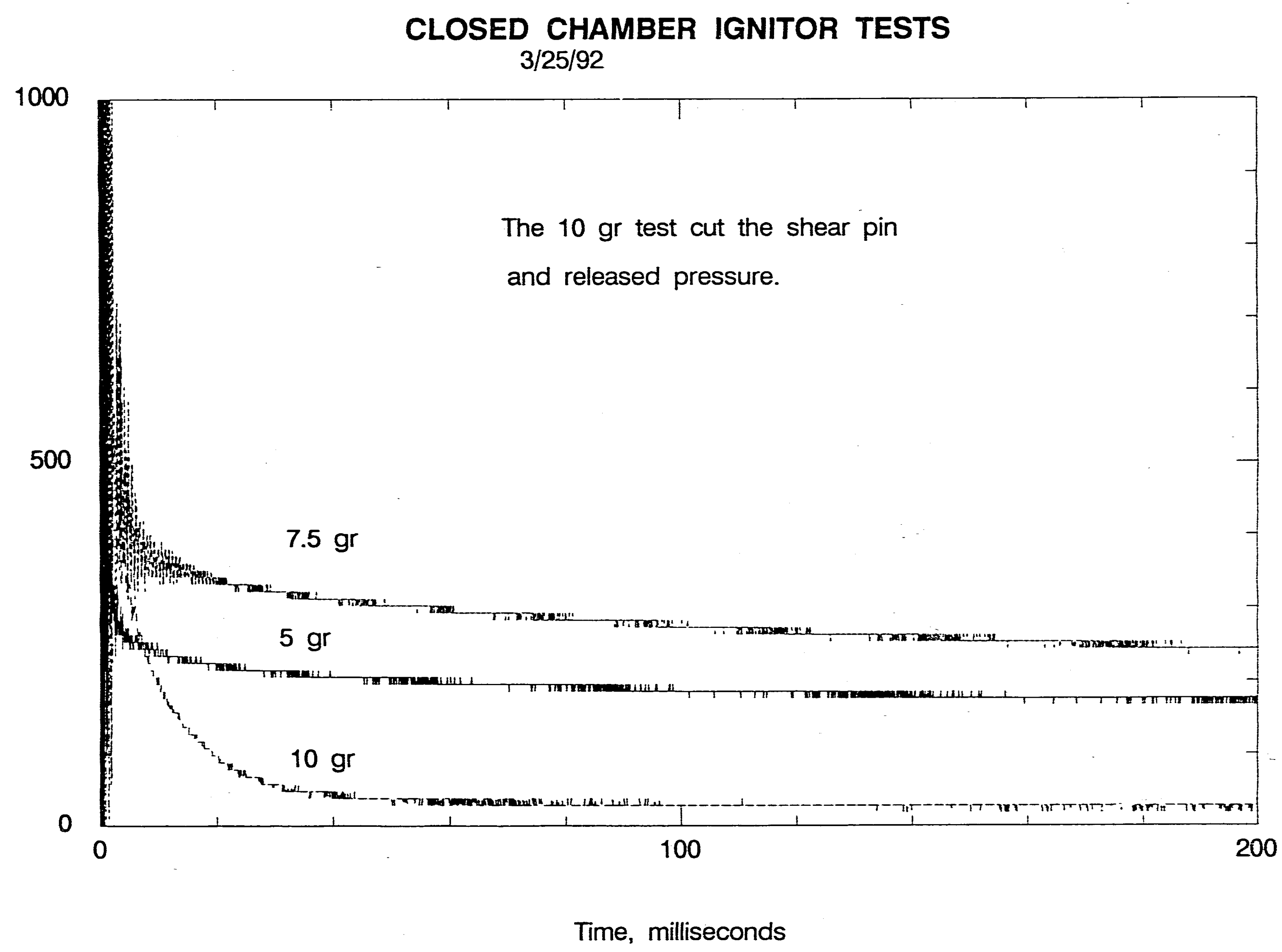

CLOSED CHAMBER IGNITOR TESTS
3/25/92
The 10 gr test cut the shear pin
and released pressure.
7.5 gr
5 gr
10 gr
1000
500
0
Pressure, psi
0
100
200
Time, milliseconds

Figure 3

```
*****************************************************************
*                     Servo-Dynamics Inc.                       *
*     STRESSFRAC Equilibrium Analysis, Ver. 1.08 2/24/92        *
*       Santa Barbara, California  (805) 967-3578               *
*****************************************************************

Prepared for:                    Telephone:
Company:        Arco Alaska      Report Date: 04-13-1992
Location:       Prudhoe Bay      Formation: Sadlerochit
Well Number:
Measured depth 9500 ft.          SD Reference #

******************** Well and Tool Data ***********************
StressFrac Tool                      Type CT Dia 2.5  in, Length 12 ft
Casing I.D.                          4.5  inches
Ambient Rock Temperature             225  deg F
True Vertical Depth                  9500  feet
Fluid type & Depth                   Water 9500  feet
Surface gas pressure                 0  psi
Fracture gradient                    .6 psi/ft.

********** Parameters of Equilibrium Fracture Model ************
Total Hydrostatic pressure           4213  psi
Closure pressure                     5700  psi
Fracture time                        .029  seconds
End effect dL/R                      .3
Number predominant fractures  2 , Perf phase  90 degrees
Assumed fracture width               .001  meters
Fraction of heat retained            .03
Gas temperature                      317.9  F

*****************  Fracture Radius Prediction  *****************

Tool dia  Average Fracture  Total Gas   Tool+Casing Tool
inches    Radius, Feet      Liters      Liters      Liters

2.375          9.3           44.6        14.5        10.5
2.5    <-*->   10.1          49.4        15.7        11.6
3              13.4          71.2        21.4        16.7

Velocity of fluid column is  6.851831  m/sec.
Acoustic wave distance is      51.87862 meters
```

Figure 4

Summary report of the Servo-Dynamics Equilibrium Volume Gas Fracture Model for a well typical of Prudhoe Bay. Note that 30% of the gas produced remains in the wellbore.

APPENDIX A
EQUILIBRIUM FRACTURE ANALYSIS

```
' GAS FRACTURE ANALYSIS, SERVO-DYNAMICS INC.
' D.T. PHILLIPS, GLENDAN COMPANY (805)967-0922
' Compile with Microsoft QuickBasic ver 4.5

version$ = " Ver. 1.08 2/24/92"

'******************* Purpose of this Program ************************
'The purpose of this program is to provide an equilibrium analysis of
'the gas production of StressFrac propellant tools, and to compute the
'expected volumetric displacement and range of fracture radius that can
'be expected as a function of tool diameter and length, well depth,
'casing size, fluid loading, temperature, and the characteristics of the
'formation. The analysis will rely on performance limits determined by
'the gas laws, together with parameters derived from actual field data.

'Computations are carried out using MKS units, though data entry and
'results will provide both MKS units and other units in common use.

'The program will provide for keyboard input of well parameters with a
screen display of resulting fracture predictions, as well as a printed
'report.


' ****************** Model Approach and Physical Laws ****************

' *** Cold Gas Volume: the minimum gas volume
' The gas law is Pamb*Vmin=N*K*TRock ,consider gas at ambient pressure & temp.
' where P= pressure in nt/m^2, V= volume m^3, N= number of molecules
' K=Boltzman's constant in joules/Kelvin and T= ambient temperature, deg K.
' for a mixed gas with components 1 and 2: P*Vmin=(P1+P2)*Vmin=(N1+N2)*K*TRock
' Solving for the volume, Vgas=(N1+N2)*K*T/P, where N1 and N2 are known from
' the tool size, and the final "cold" temperature and pressure are known
' functions of the well depth. Minimum work = Vfrac*Pamb

' *** Adiabatic Expansion: the ideal (unattainable) case of no heat loss
'     gives maximum estimate of work done on fractures.

' P*V^gamma=c1=P1*V1^gamma  where gamma=cp/cv, ratio of specific heat
' using P*V=N*K*T  gives T*V^(gamma-1)=c2
' Work done in adiabatic expansion is N*K*T1/(gamma-1)*(1-(V1/V2)^(gamma-1))
' Initial P1=N*K*T1/V1, know V1, T1, compute P1*V1^gamma=c1=N*K*T1*V^(gamma-1)
' Expand to P2=Pamb then V2=c1/Pamb^(-gamma) , maximum gas volume estimate
' To do this correctly requires disassociation at high temperatures which
' tends to soak up energy and keep the temperature down.

' gamma CO =1.40, gamma CO2=1.29 ? 50/50 mix by mass or number? gamma=1.345
' CO2: Cp=850, Cv=657 J/KgK, mol wt 44.01
' CO:  Cp=1040, Cv=741 J/KgK, mol wt 28.01

' Take 50% by mass for each CO and CO2  this means more CO molecules

' Number average molecular weight  M=A*M1+(1-A)M2; A is number fraction of M1
' Weight Average molecular weight  M=M1*M2/(M2*X+M1*(1-X)); X = wt frac of M1


' Assume 1000 CAL/GM chemical energy release, 10^6 Cal/Kg x 4.184 J/CAL
' 4.184 MJ/Kg = U
' If energy were released at constant volume U=Cv*(T2-T1) J/Kg
```

```
' T1=TRock+U/Cv=TRock+ 4.184 E6/700=TRock + 5977 (seems  high), 2000 deg Kbetter
' Zucker gives Cv CO2=657 j/kgK and CO=741 near room temp and 1 atm

'
' *** Fracture volume and fracture radius
' V = Vfrac + Vtool + Vfluid + Vloss

' The total gas volume V is occupies several reqions of interest:
' 1.  FracVol, the fracture volume,
' 2.  Vtool, the initial volume of the solid fuel,
' 3.  LiftVol, the volume created by fluid motion in the well casing,
' 4.  PorVol, gas lost to porosity , not implemented yet

' *** Fracture geometry, an elementary approach
' Vfrac = Wfrac*Nfrac*Rfrac*(Ltool+End*Rfrac)

' Fractures tend to initiate in planes containing the axis of the tool
' though the final development of each fracture is sensitive to the
' condition of the formation, including pre existing stress and variations
' in fracture strength. We assume here that each fracture is a rectangular
' sheet with width called the fracture radius, Rfrac and length equal to
' the tool length, Ltool, plus 10 to 30% of the frac radius (an end effect).
' There are commonly from 1 to 5 major fractures generated, NumFrac=1..5,
' depending on formation structure and the rate of rise of the pressure
' pulse. The total fracture area, Afrac, is then, for Endfrac=.3
' Afrac=NumFrac*Rfrac*(Ltool+Endfrac*Rfrac)
' Though during their formation, fractures have a complex wedge shape,
' we will start by assuming a constant width for the fractures, Wfrac.
' The fracture volume is then simply Vfrac=Wfrac * Afrac.

' *** Default Ambient Temperature Gradient (can overide for special cases)

' TRockF= (60 + 2/100 * depth(ft))deg F
' TRockK=273 +5/9(-32+60+2/100*depth(m)*100/(2.54*12) )deg K  ft=m/.3048


' ********************** Constants and Initialize ******************
Initialize:

   DIM DiaTool(15), Tool$(15), FluidDensity(10), Fluid$(10), ShockVel(10)
   DIM H$(11, 7), T$(11, 7)'History and treatment arrays initially ______
   FOR j = 0 TO 10
   FOR k = 0 TO 6
   H$(j, k) = " __________"
   NEXT k
   FOR k = 0 TO 6
   T$(j, k) = " __________"
   NEXT k
   NEXT j
   'constants and defaults
   pi = 4 * ATN(1)
   KBoltz = 1.38062E-23                    'Joules/degree Kelvin
   Navagodro = 6.02217E+23                 'molecules per mol
   ToolDensity = 1600                      '1.6 g/cc 1600 kg/m^3
   CGToolEnergy = 1000                     '1000 cal/gm
   ToolEnergy = 1000 * CGToolEnergy / .2388  'Joules/Kg
   RockDensity = 2200                      'Kg/m^3 estimate overburden
   TempGradient = 2 / 100 * 3.2808 * 5 / 9'Degrees K /m from 2degF/100ft
   SurfaceTemp = (60 - 32) * 5 / 9 + 273.15 'Degrees K Nominal surface
   FracGradf = 1                           ' Default 1 psi/ft closure pressure
   CaseIDin = 5                            ' Default 5 inch casing
   depthf = 5000                           ' default 5000 ft depth
```

```
   Tmeasf = 160                              'default temp deg f
   FluidHtf = 5000                           ' default fluid ht 5000 ft
   FluidHt = FluidHtf * .3048                ' convert fluid ht to meters
   TestTool = 4                              'default to 2 inch tool
   SmallerTool = 3                           '
   ToolLenft = 12                            'default 12 foot
   REnd = .3                                 'dL/R extension of fracture at end
   Nfrac = 2                                 'Assumed number of fracture wings
   Tfrac2 = .015                             'Radial Time of max fracture for 2 in tool
   LongVel = 1200 * .3048                   'Longitudinal ignition velocity m/sec
   GasHeat = .03                             'Heat in Gas is 3% up from Ambient
   FluidNum = 1                              'Start with water
   Wfrac = .001                              '1 mm fracture width assumed
   Gamma = 1.345                             'average CO and CO2
   Cv = 700                                  'ave specific heat j/degKkg for gas
   Tooltype$ = "CT"
   Details$ = "N"                            'default omits calculation details
   PrintText$ = "N"                          'Default skips model explanation
   Toolsize$ = "STD"
   Bottom$ = "N"                             'compress fluid both up & down
   Count = 1                                 'count reports generated

   Mix = .5   'Gram Mol Wt of CO2=44.01, of CO=28.01
   GasMolWt = 44.01 * 28.01 / (28.01 * Mix + 44.01 * (1 - Mix))
   'for Mix fraction of CO2 by weight in CO2 and CO gas.
   REM GasMolWt= Mix*44.01 +(1-Mix)*28.01
   'for Mix fraction of CO2 by number in CO2 and CO gas.
'********************** Fluid Names ***************************
   Fluid$(1) = " Water"
   Fluid$(2) = " 1% KCl Solution"
   Fluid$(3) = " Sea Water"
   Fluid$(4) = " Crude Oil"
   Fluid$(5) = " Liquid CO2"
   TotFluids = 5

'****************  Table of StressFrac Tool Diameters  *********
   Tool$(1) = "0.183"  'Nominal 1/4 inch has .183 inside alum tube
   Tool$(2) = "1.25 "
   Tool$(3) = "1.625"
   Tool$(4) = "2    "
   Tool$(5) = "2.375"
   Tool$(6) = "2.5  "
   Tool$(7) = "3    "
   Tool$(8) = "3.5  "
   Tool$(9) = "4    "
   Tool$(10) = "4.5  "
   TotTools = 10
   Tool$(0) = "2    " 'Default tool diameter at start of session

'*********************** Commands & Menu System *********************
mainloop: 'replace this with pull down menus as time permits
CLS
PRINT "STRESSFRAC Equilibrium Fracture Analysis"
PRINT version$
PRINT
PRINT "1.  Enter Well Identification"
PRINT "2.  Enter Well Parameters"
PRINT "3.  View Results"
PRINT "4.  Print Report"
PRINT "5.  Save Report in a File"
PRINT "6.  Change Model Parameters"
PRINT
```

```
PRINT "Enter your choice 1,2,3,4,5,6 or X to exit program"

wait1: a$ = INKEY$
IF a$ = "" THEN GOTO wait1

IF a$ = "1" THEN GOSUB WellIdentification
IF a$ = "2" THEN GOSUB WellData
IF a$ = "3" THEN GOSUB ScreenOut
IF a$ = "4" THEN GOSUB PrintOut
IF a$ = "5" THEN GOSUB FileOut
IF a$ = "6" THEN GOSUB Options
IF a$ = "X" OR a$ = "x" THEN END
GOTO mainloop


'************************** Data Entry ******************************
WellIdentification:
 CLS
 PRINT "Servo-Dynamics Equillibrium Fracture Analysis"; version$
 PRINT "Todays date "; DATE$
 PRINT
 PRINT "Enter or Edit Well Identification Data. Press Enter to skip item."
 PRINT
 PRINT "Contact person  "; person$; : INPUT a$: IF a$ <> "" THEN person$ = a$
 PRINT "Contact phone#  "; phone$; : INPUT a$: IF a$ <> "" THEN phone$ = a$
 PRINT "Company name    "; company$; : INPUT a$: IF a$ <> "" THEN company$ = a$
 PRINT "Field Name      "; field$; : INPUT a$: IF a$ <> "" THEN field$ = a$
 PRINT "Formation type  "; formation$;
        INPUT a$: IF a$ <> "" THEN formation$ = a$
 PRINT "Well number     "; well$; : INPUT a$: IF a$ <> "" THEN well$ = a$
 PRINT "Measured Zone Depth, ft"; mdepthf;
        INPUT a$: IF a$ <> "" THEN mdepthf = VAL(a$)
 PRINT "Servo-Dynamics Job #"; SDJob$; : INPUT a$: IF a$ <> "" THEN SDJob$ = a$
 PRINT
 PRINT "All entries OK  (Y/N)";
        INPUT a$: IF (a$ = "y" OR a$ = "Y") THEN RETURN
        GOTO WellIdentification 'must enter y to stop editing


WellData: '******************  Description  ********************
 CLS
 PRINT "Servo-Dynamics Equilibrium Fracture Analysis"; version$
 PRINT "Enter and Edit Tool & Well Parameters. Press Enter to skip item."
 PRINT

 PRINT "STRESSFRAC tool type is           "; Tooltype$; " ";    'usually CT, tandem
        INPUT a$: IF a$ <> "" THEN Tooltype$ = a$

 PRINT "STRESSFRAC Tool Diameter, inches   "; Tool$(0); : INPUT a$:
       IF a$ <> "" THEN Tool$(0) = a$
       Toolsize$ = "SPL": SmallerTool = 0: TestTool = 0
       FOR j = 1 TO TotTools
             IF VAL(Tool$(j)) = VAL(Tool$(0)) THEN
                TestTool = j
                Toolsize$ = "STD"
             END IF
             IF VAL(Tool$(j)) < VAL(Tool$(0)) THEN SmallerTool = j
       NEXT j
        ' Now know if tool is special, "0" or standard 1-TotTools

 PRINT "Tool Diameter "; Tool$(0); " inches, is a "; Toolsize$; " diameter."
 PRINT "STRESSFRAC Tool Length, feet      "; ToolLenft;
```

```
        INPUT a$: IF a$ <> "" THEN ToolLenft = VAL(a$)

 PRINT "Casing I.D. , inches                  "; CaseIDin;
        INPUT a$: IF a$ <> "" THEN CaseIDin = VAL(a$)

 PRINT "Perforation phasing, degrees          "; Perfdeg;
        INPUT a$: IF a$ <> "" THEN Perfdeg = VAL(a$)
        'assume 2 dominant fracture wings, can change in model parameter menu

 PRINT "True Vertical Zone depth, feet        "; depthf; : INPUT a$:
        IF a$ <> "" THEN
        depthf = VAL(a$)
        FluidHtf = depthf: FluidHt = FluidHtf * .3048 'change fluid to match
        Tmeasf = 60 + .02 * depthf       'estimate temp when depth is changed
        END IF

 PRINT "Ambient temperature, deg F            "; Tmeasf;
        INPUT a$: IF a$ <> "" THEN Tmeasf = VAL(a$)
        'When zone depth is entered, Temp is estimated at 60+2 deg F/100 ft

 PRINT "Fracture gradient psi/ft              "; FracGradf;
        INPUT a$: IF a$ <> "" THEN FracGradf = VAL(a$)
 PRINT "Fluid Column Height, feet            "; FluidHtf; : INPUT a$
        IF a$ <> "" THEN
        FluidHtf = VAL(a$)
        FluidHt = FluidHtf * .3048       'meters
        END IF

 PRINT "Select fluid type by pressing Spacebar, enter to accept": j = 0
 ' find nice menu commands to avoid this mess
wait7: a$ = INKEY$: IF (a$ = "") THEN GOTO wait7
       IF a$ = CHR$(13) THEN GOTO endfluid
       IF a$ = " " THEN j = j + 1
       IF j > TotFluids THEN j = 1
       PRINT TAB(1); "Fluid type is   "; Fluid$(j); "           "; CHR$(30);
       FluidNum = j
GOTO wait7
endfluid: PRINT TAB(1); "Fluid type is   "; Fluid$(FluidNum)

 PRINT
 PRINT "All values OK? (y/n)";
        INPUT a$: IF (a$ = "y" OR a$ = "Y") THEN RETURN 'to main menu
        GOTO WellData  'another chance to enter data, must say y to get out
```

```
'**************************** Options *********************************
Options: 'Change fracture model parameters
 CLS
 PRINT "Servo-Dynamics Equillibrium Fracture Analysis"; version$
 PRINT "Todays date "; DATE$
 PRINT
PRINT "Edit Fracture Model Parameters. Press Enter to skip"
PRINT
PRINT "End Effect: dL/R (0 to 1)        "; REnd;
       INPUT a$: IF a$ <> "" THEN REnd = VAL(a$)
       IF REnd < 0 THEN REnd = 0
       IF REnd > 1 THEN REnd = 1

PRINT "Number of Fracture Wings         "; Nfrac;
       INPUT a$: IF a$ <> "" THEN Nfrac = INT(.5 + VAL(a$))
       IF Nfrac < 1 THEN Nfrac = 1

PRINT "Radial Burn Time, 2in tool, sec "; Tfrac2;
       INPUT a$: IF a$ <> "" THEN Tfrac2 = VAL(a$)
       IF Tfrac2 < 0 THEN Tfrac2 = 0
       IF Tfrac2 > 10 THEN Tfrac2 = 10

PRINT "Longitudinal Ignition Velocity  "; LongVel; " meters/sec";
       INPUT a$: IF a$ <> "" THEN LongVel = VAL(a$)

PRINT "Heat Retention Fraction (0tol)  "; GasHeat;
       INPUT a$: IF a$ <> "" THEN GasHeat = VAL(a$)
       IF GasHeat < 0 THEN GasHeat = 0
       IF GasHeat > 1 THEN GasHeat = 1

PRINT "Assumed Fracture Width, meters  "; Wfrac;
       INPUT a$: IF a$ <> "" THEN Wfrac = VAL(a$)

PRINT "Is tool at bottom of hole? (Y/N)   "; Bottom$;
       INPUT a$: IF a$ <> "" THEN Bottom$ = a$

PRINT "Gas Pressure on fluid column, psi"; GasPresPSI;
       INPUT a$: IF a$ <> "" THEN GasPresPSI = VAL(a$)

PRINT "Print descriptive text (Y/N)       "; PrintText$; : INPUT a$
       IF a$ <> "" THEN
          IF a$ = "y" OR a$ = "Y" THEN PrintText$ = "Y"
          IF a$ = "n" OR a$ = "N" THEN PrintText$ = "N"
       END IF

PRINT "Print calculation details (Y/N)    "; Details$; : INPUT a$
       IF a$ <> "" THEN
          IF a$ = "y" OR a$ = "Y" THEN Details$ = "Y"
          IF a$ = "n" OR a$ = "N" THEN Details$ = "N"
       END IF
PRINT
PRINT "Are all values OK  (Y/N)  ";
       INPUT a$: IF (a$ = "y" OR a$ = "Y") THEN RETURN
       GOTO Options ' must enter y to leave menu

'**************************** Printed Report *************************
ScreenOut:
      Outmode$ = "Screen": m$ = ""
      CLS
      OPEN "con" FOR OUTPUT AS #3
      GOSUB Report
```

```
        CLOSE #3
        RETURN 'to main menu

PrintOut:
        m$ = "         "'margin for printing
        CLS : PRINT : PRINT : PRINT "    Printing Report ..."
        Outmode$ = "Print"
        OPEN "lpt1" FOR OUTPUT AS #3
        GOSUB Report
        PRINT #3, CHR$(12); 'new page
        CLOSE #3
        RETURN 'to main menu

FileOut:
        m$ = "       " 'Save as it is printed
        Outmode$ = "File"
        CLS
        'generate name from company$ and date and session count
        'Name, mo, day,.,year,count
        'get 99 counts/day, can search company or yr
        Count$ = STR$(Count): j = LEN(Count$): Count$ = MID$(Count$, 2, j - 1)
        IF LEN(Count$) = 1 THEN Count$ = "0" + Count$

        OutFile$ = LEFT$(company$, 4) + MID$(DATE$, 4, 2) + LEFT$(DATE$, 2)
        OutFile$ = OutFile$ + "." + RIGHT$(DATE$, 1) + Count$
        'put report in current directory
OutName:
        PRINT "Press Enter to Accept Suggested  Filename, or enter new name"
        PRINT "DOS Filename for report ( COMPDDMM.YCC )"; OutFile$; " OK";
        INPUT a$
        IF a$ <> "" THEN OutFile$ = a$
        IF LEN(OutFile$) > 12 THEN GOTO OutName
        IF LEN(OutFile$) = 12 AND MID$(OutFile$, 9, 1) <> "." THEN GOTO OutName
        PRINT "Saving File  "; OutFile$
        OPEN OutFile$ FOR OUTPUT AS #3
        GOSUB Report
        CLOSE #3
        Count = Count + 1: IF Count > 99 THEN Count = 1
        RETURN ' to main menu

Report: '************** Main Computation and Output ******************
'First, a few computational details to clean up. Fluid data grouped here
'for convenience.

           '*** clean up units for calculation ***
    depth = depthf * .3048              'feet to meters
    Tmeas = 273.15 + 5 / 9 * (Tmeasf - 32) 'deg F to deg K
    CasingID = CaseIDin * .0254          'inches to meters
    ToolLength = ToolLenft * .3048       'ft to meters
    PfracPSI = INT(.5 + FracGradf * depthf)     'use measured psi/ft
    Pfrac = PfracPSI * 9.8 / (2.2 * .0254 ^ 2)    'convert to nt/m^2
```

```
'*******************  Fluid Properties ************************
'  Need depth to get accurate velocity and density numbers for compression

'  Fluid$(1) = " Water"
   FluidDensity(1) = 997 + .0045 * depth              'Kg/M^3
   ShockVel(1) = 1493.2 + .018 * depth                'm/sec = 4,967 ft/sec
' 25 deg C density is .99707, increases by 4.5E-6 g/cc per meter depth
' sound velocity is 1493.2 m/s, increases by .018 m/s per meter depth


'  Fluid$(2) = " 1% KCl Solution"
   FluidDensity(2) = 1005                   'Kg/M^3   .435 psi/ft =1005.5
   ShockVel(2) = ShockVel(1) + 3.3                     'a bit more than H2O
'at 30 deg C 0.4 mol/liter KCl adds 10 m/s , KCl=39.0983+35.4527=74.5 g/mol
'1%=10g/L or .1341 mol/L so dV=10*.1341/.4=3.3 m/s not much change

'  Fluid$(3) = " Sea Water"
   FluidDensity(3) = 1024                   'Kg/M^3 Get a Number!!
   ShockVel(3) = 1536                       'Get a Number

'  Fluid$(4) = " Crude Oil"
   FluidDensity(4) = 867                    'Kg/M^3   .375 psi/ft=866.7
   ShockVel(4) = 1300                       'M/sec GET A  NUMBER!!
'Heptane density .681, velocity 1165
'Octane density  .702, velocity 1238
'Kerosene         .810          1315
'Naptha           .760          1225

'  Fluid$(5) = " Liquid CO2"                'wild guesses on density and vel
   FluidDensity(5) = 700                    'Kg/M^3  Get a Number
   ShockVel(5) = 1000                       'M/sec GET A NUMBER!!!
```

```
'************ Now Begin Output of Formated Report, Compute as we go ********

 PRINT #3,

 m = LEN(m$)'margin
 PRINT #3, m$; "******************************************************************"
 PRINT #3, m$; "*                    Servo-Dynamics Inc.                          *"
 PRINT #3, m$; "*     STRESSFRAC Equilibrium Analysis,"; version$; TAB(m + 64); "*"
 PRINT #3, m$; "*      Santa Barbara, California  (805) 967-3578                 *"
 PRINT #3, m$; "******************************************************************"
 PRINT #3,
 PRINT #3, m$; "Prepared for:  "; person$; TAB(40); "Telephone:   "; phone$
 PRINT #3, m$; "Company:       "; company$; TAB(40); "Report Date: "; DATE$
 PRINT #3, m$; "Location:      "; field$; TAB(40); "Formation: "; formation$
 PRINT #3, m$; "Well Number:   "; well$
 PRINT #3, m$; "Measured depth"; mdepthf; "ft."; TAB(40); "SD Reference # "; SDJob$
 GOSUB Screenwait
 PRINT #3,
 PRINT #3, m$; "******************** Well and Tool Data **********************"
 GOSUB WellSetup
 PRINT #3, m$; "StressFrac Tool               ", " Type "; Tooltype$; " Dia ";
Tool$(TestTool); "in, Length"; ToolLenft; "ft"
 PRINT #3, m$; "Casing I.D.                  ", CaseIDin; " inches"
 PRINT #3, m$; "Ambient Rock Temperature", TRockF; " deg F"
 PRINT #3, m$; "True Vertical Depth     ", depthf; " feet"
 PRINT #3, m$; "Fluid type & Depth      ", Fluid$(FluidNum); FluidHtf; " feet"
 PRINT #3, m$; "Surface gas pressure    ", GasPresPSI; " psi"
 PRINT #3, m$; "Fracture gradient       ", FracGradf; "psi/ft."
 PRINT #3,
 PRINT #3, m$; "********** Parameters of Equilibrium Fracture Model ***********"
 PRINT #3, m$; "Total Hydrostatic pressure", PHydroPSI; " psi"
 PRINT #3, m$; "Closure pressure          ", PfracPSI; " psi"
   ToolNum = TestTool: GOSUB Tool          'compute lift and Tfrac
   Tfrac3 = INT(.5 + Tfrac * 1000) / 1000  'format to 3 places
 PRINT #3, m$; "Fracture time             ", Tfrac3; " seconds"
 PRINT #3, m$; "End effect dL/R           ", REnd
 PRINT #3, m$; "Number predominant fractures "; Nfrac; ", Perf phase "; Perfdeg;
"degrees"
 PRINT #3, m$; "Assumed fracture width    ", Wfrac; " meters"
 PRINT #3, m$; "Fraction of heat retained ", GasHeat
 PRINT #3, m$; "Gas temperature           ", TgasF; " F"

 GOSUB Screenwait
 PRINT #3,
 PRINT #3, m$; "*****************  Fracture Radius Prediction  ****************"
 PRINT #3,
 PRINT #3, m$; "Tool dia  Average Fracture  Total Gas   Tool+Casing Tool"
 PRINT #3, m$; "inches    Radius, Feet      Liters      Liters      Liters"
 PRINT #3,

IF TestTool <> 0 THEN  'its a standard tool, so print out 3 in a row
     LowTool = TestTool - 1
     IF LowTool <= 0 THEN LowTool = 1
     HiTool = TestTool + 1
     IF HiTool >= TotTools THEN HiTool = TotTools
     FOR ToolNum = LowTool TO HiTool
     GOSUB Printline
     NEXT ToolNum
ELSE    ' non-standard tool size, try to bracket with standard tools

     IF SmallerTool >= 1 AND SmallerTool <= TotTools THEN
```

```
        ToolNum = SmallerTool          'print next smaller tool
        GOSUB Printline
        END IF

        ToolNum = 0                     'print special tool
        GOSUB Printline

        HiTool = SmallerTool + 1        'print next larger tool
        IF HiTool <= TotTools THEN
        ToolNum = HiTool
        GOSUB Printline
        END IF
END IF
GOSUB Screenwait
GOTO ModText

Printline: ' Just print out three cases of ToolnNum around choice TestTool
    Mark$ = ""
    IF ToolNum = TestTool THEN Mark$ = "<-*->"
    GOSUB GasVol
    PRINT #3, m$; Tool$(ToolNum); TAB(m + 8); Mark$; TAB(m + 15); FracRadFt; TAB(m +
29); VgasL; TAB(m + 41); LTVL; TAB(m + 53); VtoolL
RETURN

ModText:
    IF PrintText$ = "N" THEN GOTO ExtraDetails
    PRINT #3,
    PRINT #3, m$; "************** The Equilibrium Fracture Model ***************"
    PRINT #3, m$; " Fracture radius is calculated from the generated gas volume."
    PRINT #3, m$; " Fracture wings are assumed rectangular, with a rectangular  "
    PRINT #3, m$; " extension beyond the end of the tool.  Fracture width is a  "
    PRINT #3, m$; " constant. Gas pressure equals the fracture closure pressure "
    PRINT #3, m$; " from known frac gradient.  Gas temperature is determined by "
    PRINT #3, m$; " ambient rock temperature plus a small fraction of the heat  "
    PRINT #3, m$; " available after adiabatic expansion of the propellant.      "
    PRINT #3, m$; " Combustion products are assumed to be half CO2 and half CO  "
    PRINT #3, m$; " by weight. Open volume in the casing is computed from the   "
    PRINT #3, m$; " compression of the casing fluid due to the pressure increase"
    PRINT #3, m$; " from hydrostatic to closure pressure during fracture growth."
    PRINT #3, m$; " Fracture growth may be enhanced by stresses and faults in   "
    PRINT #3, m$; " formation, well beyond the average values computed here.    "
GOSUB Screenwait

ExtraDetails:

    PRINT #3,
    IF Details$ = "N" THEN GOTO NoDetails
    PRINT #3, m$; "Velocity of fluid column is "; Pvel; " m/sec."
    j = ShockVel(FluidNum) * Tfrac'Distance traveled by shock wave
    PRINT #3, m$; "Acoustic wave distance is      "; j; "meters"

GOSUB Screenwait
NoDetails:
RETURN       '********* End of Report ************* return to output caller
```

```
'**************************** Gas Law Computations ***********************

WellSetup:
    TRock = Tmeas               'in deg kelvin use measured T if avail
    TRockF = INT(.499 + 10 * (32 + (TRock - 273.15) * 9 / 5)) / 10'deg K to deg F
    PHydro = FluidDensity(FluidNum) * FluidHt * 9.8'Hydrostatic p in nt/m^2
    PHydro = PHydro + GasPresPSI / (.00001 * 14.7) 'add surface pressure
    PHydroPSI = INT(.499 + PHydro * .00001 * 14.7)      'convert to psi


'     PRock = RockDensity * depth * 9.8             'Formation overburden
'     ProckPSI = INT(.499 + PRock * .00001 * 14.7)            'convert to psi

'Calculate the temperature, Tadiabat:propellent adiabatically expands to Pfrac
 TBurn = ToolEnergy / Cv          'Idealized burn temperature at constant vol
 Nunit = Navagodro * ToolDensity * 1000 / GasMolWt 'Number molecules in unit vol
 Pburn = Nunit * KBoltz * TBurn                     'P=NKT/V,V=1

'For Adiabatic expansion P*V^Gamma is constant. New pressure is rock pressure
 Vadiabat = EXP((1 / Gamma) * LOG(Pburn / Pfrac))     'Since Vburn=1
 Tadiabat = Pfrac * Vadiabat / (Nunit * KBoltz)       'T=PV/NK
'Tadiabat is max "Flame Temperature" for the expanded gases with no heat loss

'Compute gas temperature, lies between rock temp and adiabatic maximum temp
   DeltaT = Tadiabat - TRock
   Tgas = TRock + GasHeat * DeltaT       'Set temp between TRock & Tadiabat
   TgasF = INT(10 * ((Tgas - 273.15) * 9 / 5 + 32) + .499) / 10'Format Farenheit
   IF DeltaT < 0 THEN Tgas = TRock           'never below ambient


RETURN

GasVol: 'calculate in MKS system
       GOSUB Tool                                ' Get tool characteristics
       Vgas = Ntool * KBoltz * Tgas / Pfrac     ' m^3 PV=NKT
       VgasL = INT(Vgas * 10000 + .5) / 10     ' convert to liters and format
       VFrac = Vgas - Vtool - LiftVol           ' Volume corrections
       GOSUB FracRadius                          ' Compute fracture radius
       FracRadFt = INT(.499 + 10 * FracRadius / .3048) / 10'meters to feet for output
       HydroEnergy = VFrac * Pfrac              'Hydrolic Fracture Energy J
       IF HydroEnergy < 0 THEN HydroEnergy = 0
       HEpercent = INT(.499 + 10000 * HydroEnergy / ETool) / 100'Format % hydro energy
RETURN

Tool: 'tool size dependent calculations: lift, tool mass etc.

  'Compute lift in fluid using shock compression of the fluid
  'This method depends on tool size through change in time, TFrac
  'Nominal value is 10 msec for 2 inch tool, and vary in proportion
  'For long tools must add longitudinal ignition time at 1200 ft/sec
    Pvel = (Pfrac - PHydro) / (FluidDensity(FluidNum) * ShockVel(FluidNum))
    IF Pvel < 0 THEN Pvel = 0
    Tfrac = Tfrac2 * .5 * (VAL(Tool$(ToolNum)) - .25) / .875'linear increase, based on
2 in
    Tfrac = Tfrac + ToolLength / LongVel    'add ignition time for long tool
    IF Tfrac < 0 THEN Tfrac = 0
    Lift = Pvel * Tfrac                       'motion of top column only
    LiftF = INT(.499 + (Lift / .3048) * 10) / 10'format and convert to feet
    CasingArea = pi / 4 * CasingID ^ 2
    Nfluid = 2                                 'Default to compress both ways
    IF Bottom$ = "Y" OR Bottom$ = "y" THEN Nfluid = 1
```

```
    LiftVol = CasingArea * Lift * Nfluid          'include fluid below the tool
    LiftVolL = INT(.499 + 10000 * LiftVol) / 10   'Format and convert to liters
    Smass   =   2   *   CasingArea   *   ShockVel(FluidNum)   *   Tfrac   *
FluidDensity(FluidNum)'top&bot
    EFluid = 2 * .5 * Smass * Pvel ^ 2            'KE + stress energy = 2* KE

' *** Fluid Displacement Volume: Shock wave approach: Assume that the fluid
'is suddenly pressurized by the gas pressure of the tool, changing from
'hydrostatic pressure to the rock pressure (ignore the important but brief
'breakdown pressure pulse).  Momentum conservation gives the important
'relation dP=Density*ShockVelocity*ParticleVelocity. Use this to compute
'velocity of the end of the column. (Note fluid below zone also compresses!)
'The burn time is an issue for very long tools, for short ones the shock
'wave does not have time to reach the surface. For now ignore coulmn length.
'ColumnMove=Tfrac*PVel*2 (for top and bottom). LiftVol=Area*ColumnMove
'Energy in each compressed coulmn is 2*.5*m*v^2


' Calculate volume, mass, energy, number of molecules
   ToolDia = VAL(Tool$(ToolNum)) * .0254          'convert inches to meters
   Vtool = .25 * pi * ToolDia ^ 2 * ToolLength    'Volume m^3
   VtoolL = INT(.499 + 10000 * Vtool) / 10          'Volume L formated
   LTVL = INT(.499 + 10 * (VtoolL + LiftVolL)) / 10'Tool&Casing in L
   Mtool = Vtool * ToolDensity                    'mass in Kg
   ETool = Mtool * ToolEnergy                     'Energy in J
   Ntool = Navagodro * Mtool * 1000 / GasMolWt    'Number of Gas Molecules
   EFluidpercent = INT(.5 + 10000 * EFluid / ETool) / 100'Format fluid E %
                       'convert Kg to Grams for Gram mol wt

    RETURN

FracRadius: ' FracVol=FracWidth*NFrac*ToolLength*FracRadius+REnd*FracRadius^2
    IF VFrac <= 0 THEN GOTO NoFrac   'Negative volume: no fractures!
    IF REnd = 0 THEN GOTO NoEnd   'Quadratic Eq blows up for REnd=0
    b = .25 * ToolLength / REnd
    FracRadius = -b + SQR(b * b + VFrac / (2 * REnd * Wfrac * Nfrac))
    RETURN
NoEnd: FracRadius = VFrac / (Nfrac * Wfrac * ToolLength)
    RETURN
NoFrac: FracRadius = 0
    RETURN


' ********************  Misc  Subroutines  **********************

Screenwait:
IF Outmode$ <> "Screen" THEN RETURN
a$ = INKEY$
IF a$ = "" THEN GOTO Screenwait
RETURN

HoldScreen:
a$ = INKEY$
IF a$ = "" THEN GOTO HoldScreen
RETURN
```

END

DATE FILMED

6/01/92