# TROPICAL WIND, ENERGY CONVERSION, REFERENCE LEVEL EXPERIMENT (TWERLE)

## Status Report

## (For the Period Ending 31 December 1972)

The major activities for this reporting period are as follows:

### Flight Data Summary Report

This report is nearing completion and it contains most of the information that has been obtained from the two balloon test flight series.

### Unit for Satellite Interface Tests

The eight data encoders and the power supply portion of this test unit are now nearing completion. Since John Kruse was working on the assembly containing the eight transmitters, progress on this portion of the test unit has been severely delayed.

### Data Encoder Check-out Unit

A large effort for this period has been in construction of a check-out instrument for evaluating the data encoder performance. This instrument is described in more detail in the attached report which describes the status of the data encoder.

### Finalizing Flight Train Hardware

The status of the flight train hardware is also described in more detail in the attached report.

### Launch Site Evaluation

Evaluation of launch sites is continuing with collection of meteorological data from Natal and Samoa. An additional visit to Samoa was made by Vin Lally, who stopped there enroute to Mother GHOST balloon flights from Australia.

### Procurement

The procurement process for purchasing radio altimeters was initiated. The procurement of six additional balloons for test flights was also initiated.

### Experiments with Liquid-Filled Pressure Sensor

Experiments were preformed to evaluate the feasibility of using a liquid-filled pressure sensor to reduce the hysterisis problem. A report on these experiments is attached.

# Flight Train Component

## Status Report

### Magnetic Cutdown:

#### Development:

The development phase of the magnetic cutdown is now complete. Final printed circuit layouts and negatives have been produced and six units have been fabricated for testing. A foam package has been designed and a foaming mold has been fabricated. More than 20 foam packages have been fabricated to test the foaming procedure.

#### Testing:

Testing is now in progress. The six units will be thermally cycled to -80° C for at least three cycles to determine if nighttime storage will damage the units. In addition, the units will be tested for operation to -40° C. Cutdowns have been flown from Ascension Island. Whenever balloons moved north of the +.25 gauss line they were successfully cut down.

#### Procurement:

Our procurement plan is to fabricate the units in-house. Assuming a successful completion of tests on the current design, a sample production run of 20 units will be started by 15 February. The fabrication of components for the magnetic sensor assembly is already well in progress. Most of the components required for 300 sensors have already been fabricated. Although we are proceeding with in-house fabrication, we are also assembling a procurement package. The procurement package will contain all the documentation necessary to describe the fabrication and testing so that others could fabricate the cutdowns.

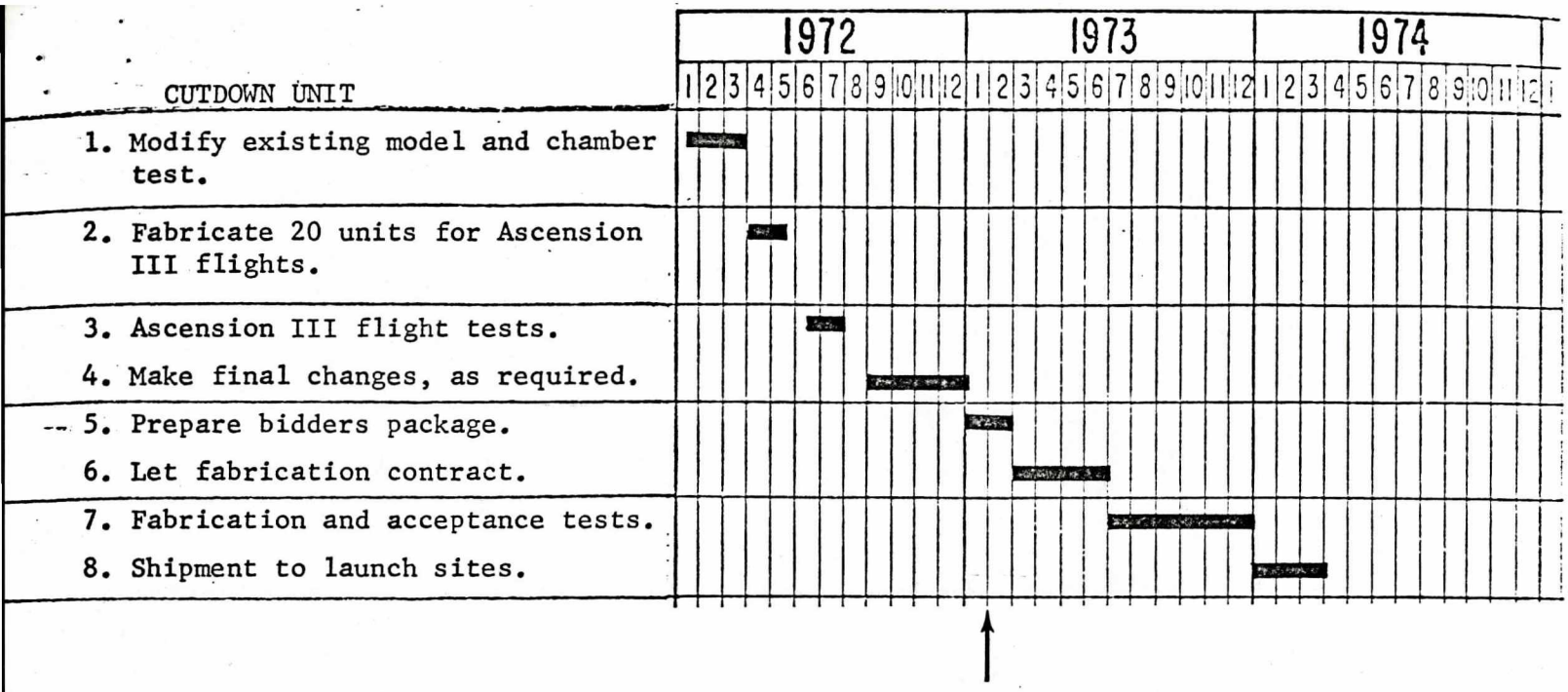
### Test and check out equipment:

Specialized test and checkout equipment will be developed, but this development has not proceeded beyond the concept stage. The test set-up will consist of essentially a fluxgate magnetometer to detect zero field, and a long solenoid for setting the magnetic field to the desired cut-down level.

### Review of Specifications:

Power: 8.5 ma from +12 volts = .102 watts (original estimate .1 watts)

Weight: 48 grams (original estimate 40 grams)


1972
1973
1974
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
CUTDOWN UNIT
1. Modify existing model and chamber test.
2. Fabricate 20 units for Ascension III flights.
3. Ascension III flight tests.
4. Make final changes, as required.
5. Prepare bidders package.
6. Let fabrication contract.
7. Fabrication and acceptance tests.
8. Shipment to launch sites.

## Solar Power Supply:

### Development:

The major effort in the solar panel development has been in evaluating fabrication techniques. The criteria for selecting the best technique is reliability, weight and cost. Three techniques have been seriously considered.

#### Technique No. 1:

Fabrication technique used in space solar panels. The cost including fabrication is greater than $2.25 per cell and there is serious doubt that this technique would produce reliable panels when mounted on a flexible substrate.

#### Technique No. 2:

Assembly on a thin printed circuit board with punched-out connection tabs. This technique is the least expensive but is unacceptable because cells tend to crack when thermally cycled.

#### Technique No. 3:

Assembly on a thin printed circuit board with thin wires. This technique allows each cell to effectively float on the mounting wires. The cost per cell is less than $1.25 and the design has been proven in test flights.

A prototype using technique No. 3 has been constructed. The final printed circuit layout is complete. A prototype foam support structure has been fabricated but some dimensional changes still need to be incorporated to adjust the foam support structure to final printed circuit dimensions.

### Testing:

The basic solar panel design has been test flown on 10 test flights from Ascension Island. Additional chamber tests and flight tests will be performed on a sample production run.

### Procurement:

The procurement plans are to fabricate in-house. A test fabrication run of 20 units will be started in late February. 80,000 cells have already been purchased and 5,000 are on hand. A jig for soldering wire to the cells has been fabricated. A jig for bending the wires for insertion into the printed circuit board has also been fabricated. This assembly equipment will be evaluated during the 20 unit assembly run.

Test and check out equipment:

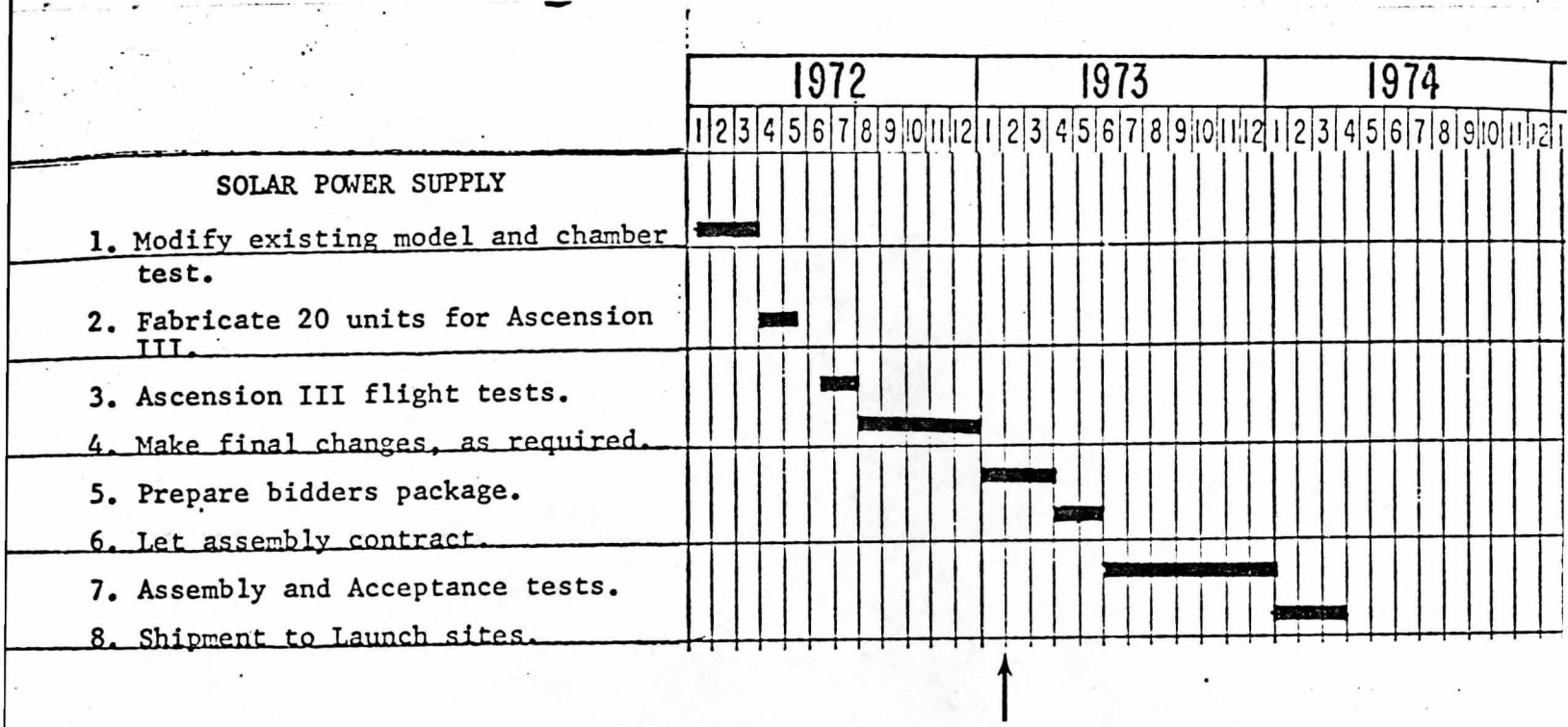
The test and check out equipment will consist of a light source to simulate solar light and meters to measure the panel output. Only conceptual drawings exist for this equipment.

Review of Specifications:

Voltage ± 12 volts

Power output: Test flights have shown that the solar panel will produce between 80 ma and 140 ma for all solar angles above 150.

Weight: 180 grams (original estimate 160-200 grams)


1972
1973
1974
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
SOLAR POWER SUPPLY
1. Modify existing model and chamber test.
2. Fabricate 20 units for Ascension III.
3. Ascension III flight tests.
4. Make final changes, as required.
5. Prepare bidders package.
6. Let assembly contract.
7. Assembly and Acceptance tests.
8. Shipment to Launch sites.

## Temperature Sensor:

### Development:

The development of the temperature sensor assembly and circuit is now complete. The final developmental step was to fabricate 10 circuits and perform tests to determine reproducability. The 10 units were also used to make component comparison tests. On the basis of these tests the final selection of a VCO module and operational amplifier module has been made. The final printed circuit layout and negatives are now complete, and several mounting structures have been fabricated.

### Testing:

Test flights from Boulder and from Ascension Island indicate that the effect of the sensor mount and balloon flight train on air temperature measurement is less than .25° C. Long time storage tests show that the maximum difference between two calibrations performed nine monts apart is .3° C. Chamber tests on the 10 evaluation units show that the maximum effect of circuit temperature on measurement accuracy is .017° C error per 1° C uncertainty in the circuit temperature. This is the maximum error and occurs for air temperature at the -40° C end of the measurement range. At the -80° C end of the range the error is almost zero.

Further testing is planned to qualify components for storage to -80° C.

### Procurement:

Our procurement plan is to fabricate the temperature sensor circuits and assemblies in-house. Fabrication of the mounting assembly is now in progress. We plan to start procurement of thermistors in early February and start fabrication of a 20 unit production run as soon as we receive shipment of the first thermistors.

The variation between thermistors is so great that it will be necessary to select circuit components for each thermistor. The result is that a thermistor and a circuit will be a matched pair.

Computer programs and techniques have been developed to select the proper component values.

In addition, each circuit must be individually calibrated.

### Test Equipment:

A test and calibration unit has been assembled for use with the temperature circuit. The calibration unit has a built in resistance box for simulating thermistor resistance, and controls for switching between air temperature reference and sensor temperature. A frequency counter is used to measure output frequency. The pre-flight check out unit will be similar except the counter will be replaced by the data Encoder check out system which will check the complete flight train.

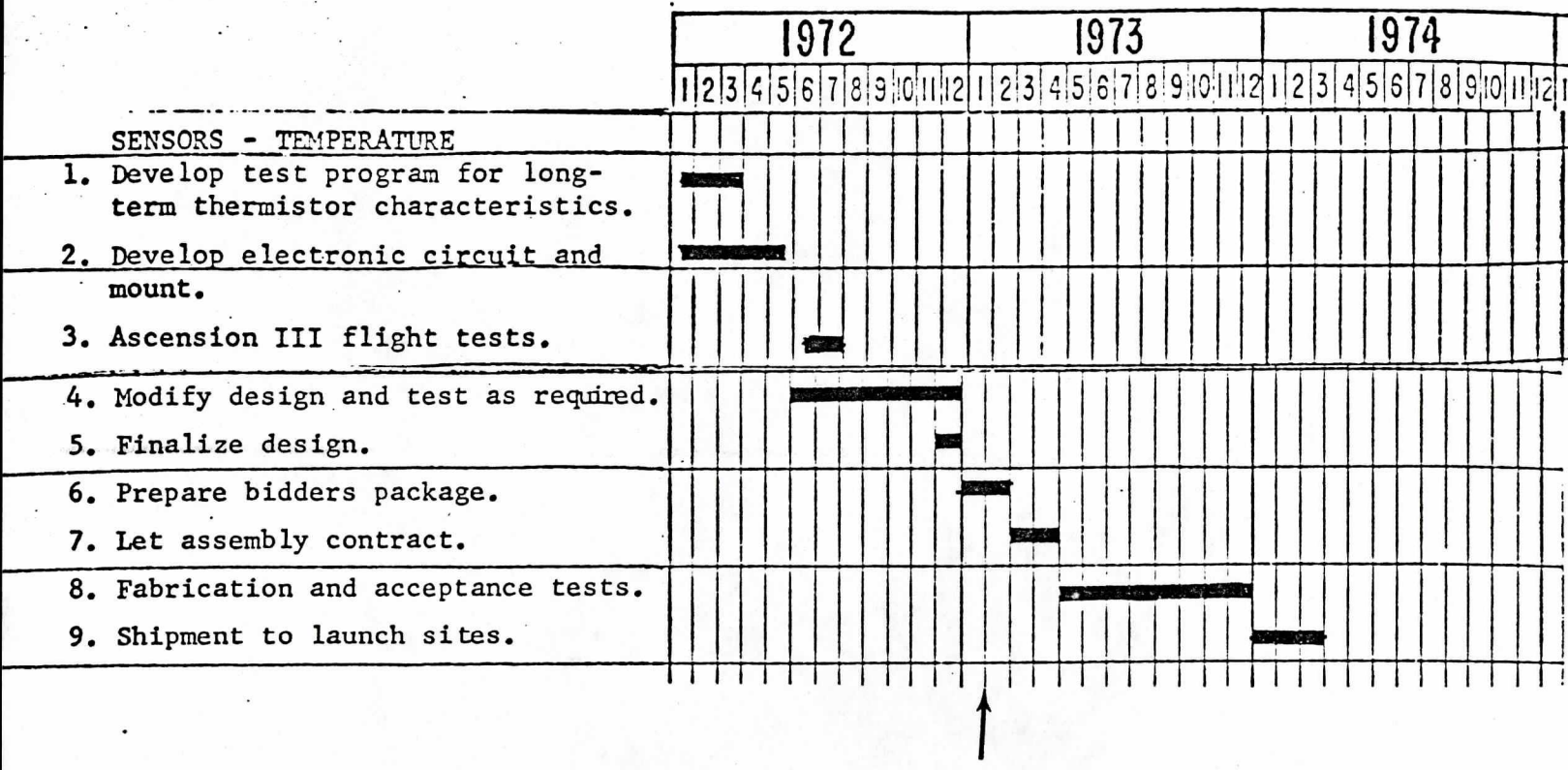
Review of Specifications:

Power: 2 ma from +12 volt supply. Original estimate was 4 ma.

Weight: 28 grams for circuit and thermistor mount. Original estimate was 20 grams.

Measurement Resolution: 0.16° C, same as original estimate.

Measurement Accuracy: 0.43° C is the estimated measurement accuracy of the air temperature sensor. The design goal was 0.5° C.


1972
1973
1974
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
SENSORS - TEMPERATURE
1. Develop test program for long-term thermistor characteristics.
2. Develop electronic circuit and mount.
3. Ascension III flight tests.
4. Modify design and test as required.
5. Finalize design.
6. Prepare bidders package.
7. Let assembly contract.
8. Fabrication and acceptance tests.
9. Shipment to launch sites.

## Data Encoder:

### Development:

The design of the Data Encoder is not complete. Before proceeding with the Data Encoder, a final decision is required to define the data word format. Also, if some of the tropical flights are to be flown without all the sensors, this decision should be made so a simplified Data Encoder can be designed for these flights.

Eleven Data Encoders have been built and are now being tested. These units have a flexible Data Format that allows for the 16 bit altitude and pressure word. The board is now designed to alternate between the 16 bit word format ant the 8 bit word format. However, we have modified one unit to transmit the 16 bit format once every four transmissions. This was done utilizing only spare gates that were already on the circuit board. In the testing of the eleven boards, several design problems were uncovered which will be corrected in the final design. The major design change will be to build the crystal oscillator circuit as a sub-assembly and to change a module in the oscillator circuit to reduce power consumption. The oscillator circuit is very sensitive to humidity, so our plan is to foam incapsulate this sub-assembly.

Eight of the current Data Encoders are now packaged as part of the TWERLE Flight platform test set.

We plan to complete the development of the Data Encoder during the month of February.

### Testing:

Some additional thermal testing will be performed on the units that we now have. These units will also be used in a system test to verify that the satellite flight platform interface is correct. The final flight configuration will be extensively tested, with special emphasis on frequency stability of the crystal oscillator sub-assembly.

### Procurement Plans:

Our procurement plan is to fabricate in-house. We plan to start fabrication of 20 units in late February to early March.

### Test Equipment:

A Data Encoder check out unit has been designed and tested. This unit accepts a Manchester data stream from either a Data Encoder or the phase detector output of a receiver. The unit bit synchronizes on the data stream, identifies and locks to the frame synchronization word. Then it displays the ID and mode bits in binary. It also, converts each of the four 8 bit data words to decimal and displays them.

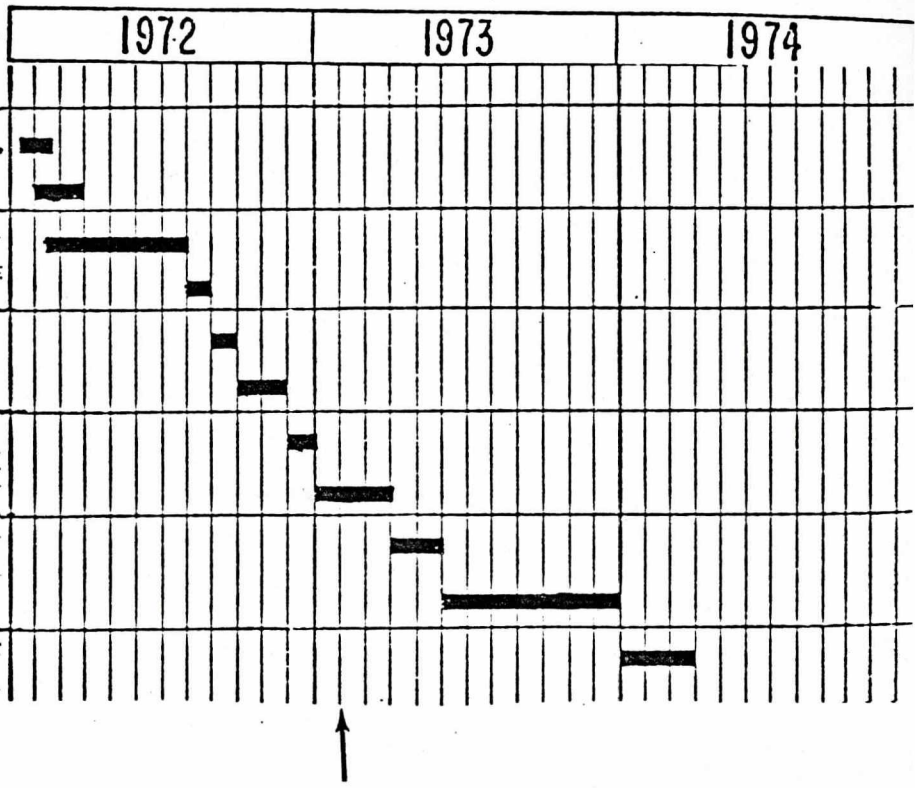
This unit is electrically working, but the packaging is not complete.

Review of Specifications:

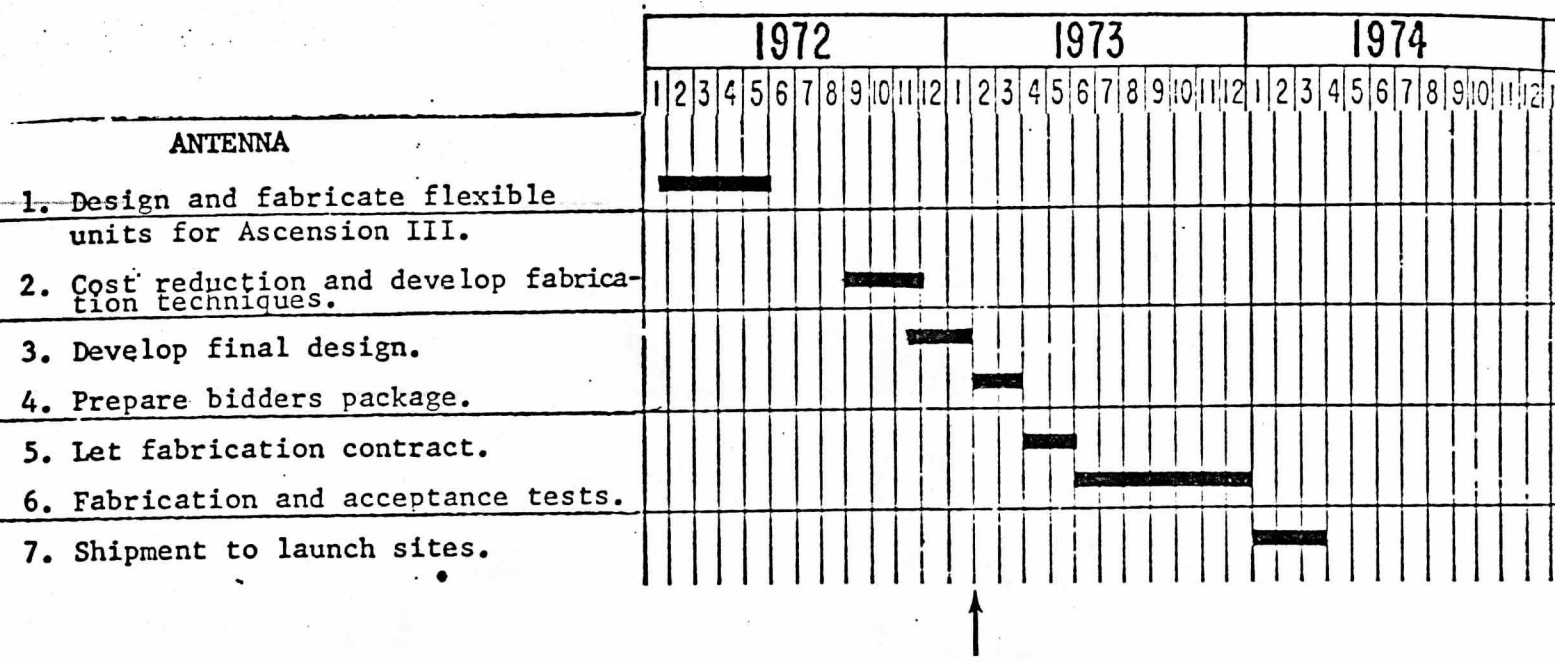
Weight: The assembled circuit weighs 87 grams. Our estimate is that with packaging we will meet the 150 gram goal.

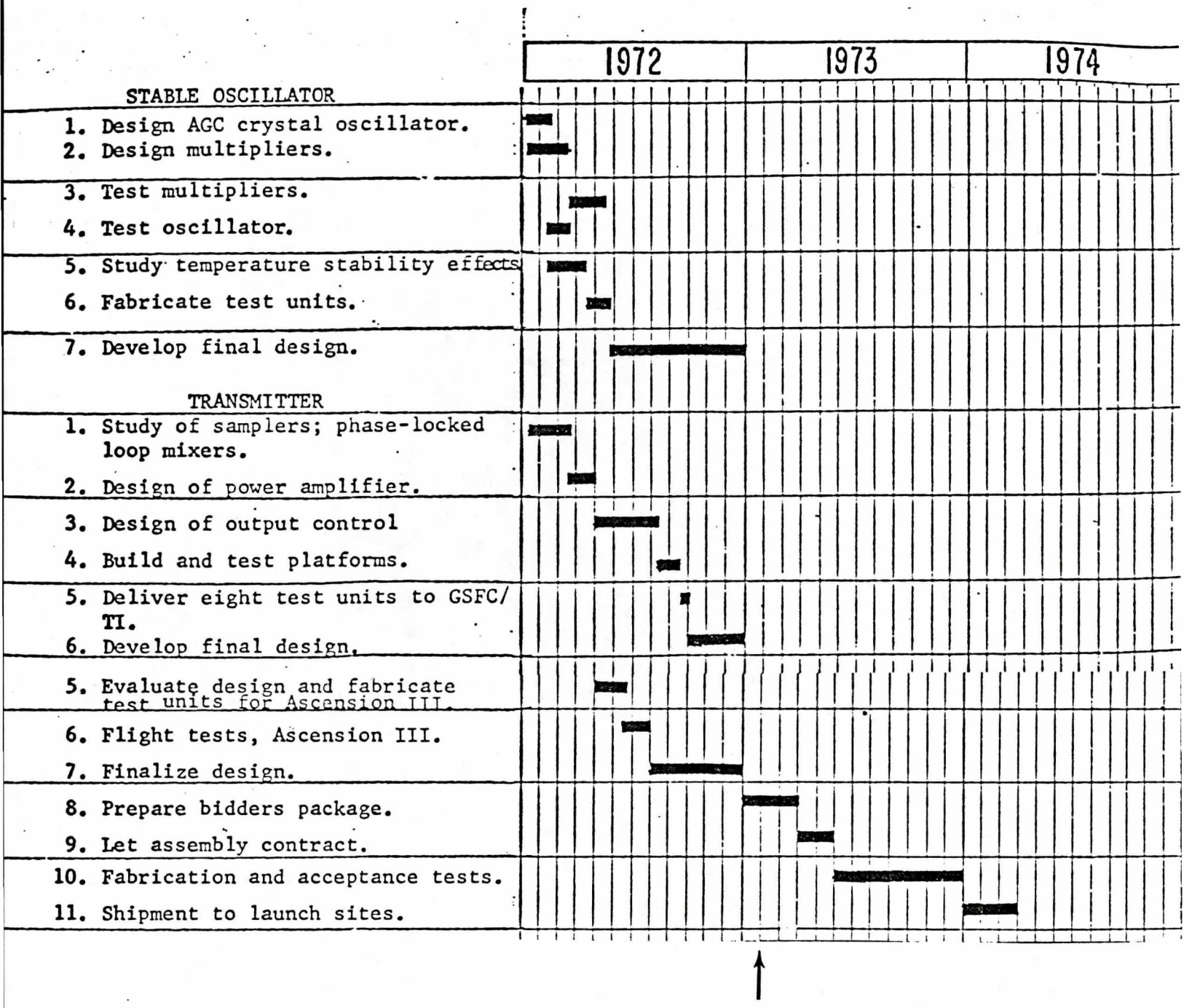
Power: The current consumption of the present design in 3 ma from a +12 volt supply. An early estimate was 10 ma.

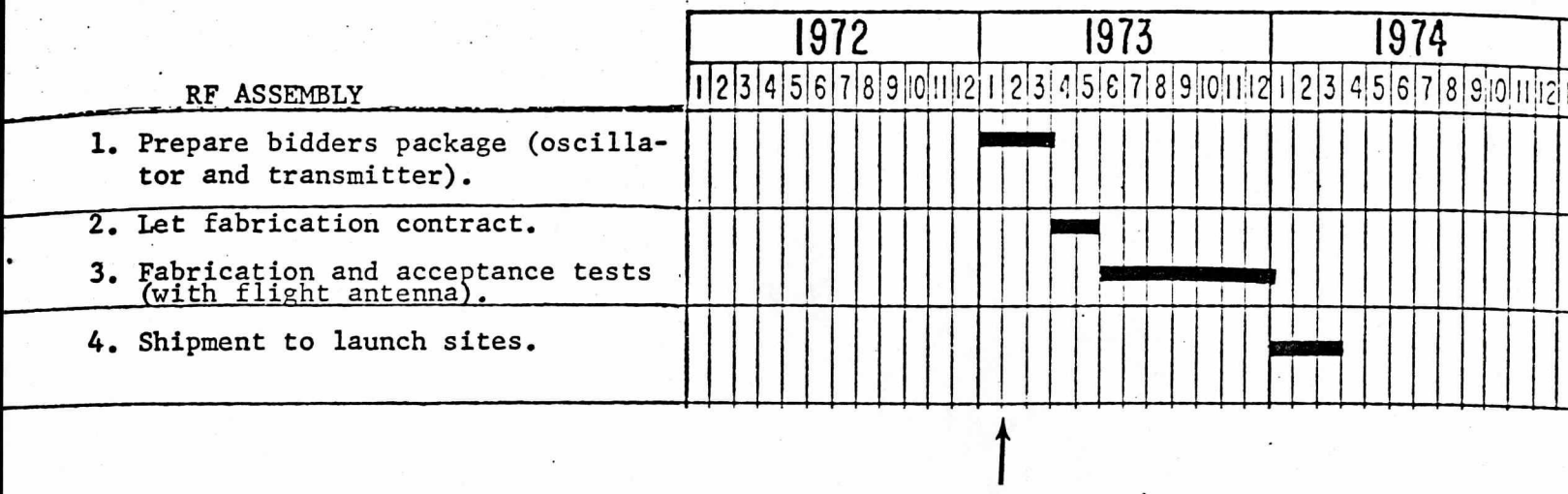
DATA ENCODER

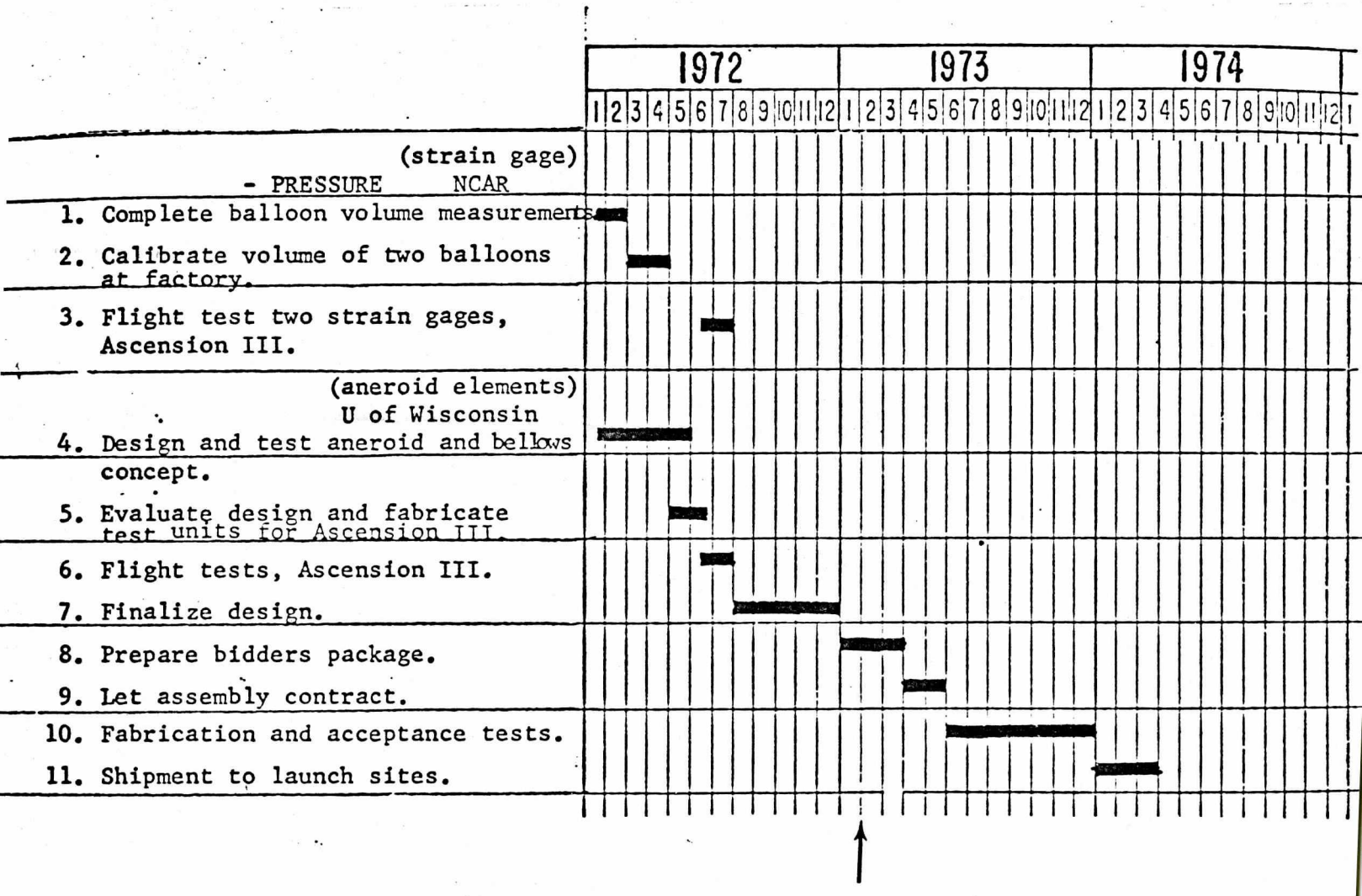



1. Resolve input/output requirements.
2. Perform component chamber tests.
3. Design and fabricate prototype.
4. Integration test.
5. Deliver 8 test units to GSFC/TI.
6. Perform flight tests.
7. Finalize design.
8. Prepare bidders package.
9. Let fabrication contract.
10. Fabrication and acceptance tests.
11. Shipment to launch sites.


1972
1973
1974
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
ANTENNA
1. Design and fabricate flexible units for Ascension III.
2. Cost reduction and develop fabrication techniques.
3. Develop final design.
4. Prepare bidders package.
5. Let fabrication contract.
6. Fabrication and acceptance tests.
7. Shipment to launch sites.


1972
1973
1974
STABLE OSCILLATOR
1. Design AGC crystal oscillator.
2. Design multipliers.
3. Test multipliers.
4. Test oscillator.
5. Study temperature stability effects
6. Fabricate test units.
7. Develop final design.
TRANSMITTER
1. Study of samplers; phase-locked loop mixers.
2. Design of power amplifier.
3. Design of output control
4. Build and test platforms.
5. Deliver eight test units to GSFC/ TI.
6. Develop final design.
5. Evaluate design and fabricate test units for Ascension III.
6. Flight tests, Ascension III.
7. Finalize design.
8. Prepare bidders package.
9. Let assembly contract.
10. Fabrication and acceptance tests.
11. Shipment to launch sites.


RF ASSEMBLY
1972
1973
1974
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
1. Prepare bidders package (oscillator and transmitter).
2. Let fabrication contract.
3. Fabrication and acceptance tests (with flight antenna).
4. Shipment to launch sites.


1972
1973
1974
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1
(strain gage)
- PRESSURE NCAR
1. Complete balloon volume measurements.
2. Calibrate volume of two balloons at factory.
3. Flight test two strain gages, Ascension III.
(aneroid elements)
U of Wisconsin
4. Design and test aneroid and bellows concept.
5. Evaluate design and fabricate test units for Ascension III.
6. Flight tests, Ascension III.
7. Finalize design.
8. Prepare bidders package.
9. Let assembly contract.
10. Fabrication and acceptance tests.
11. Shipment to launch sites.

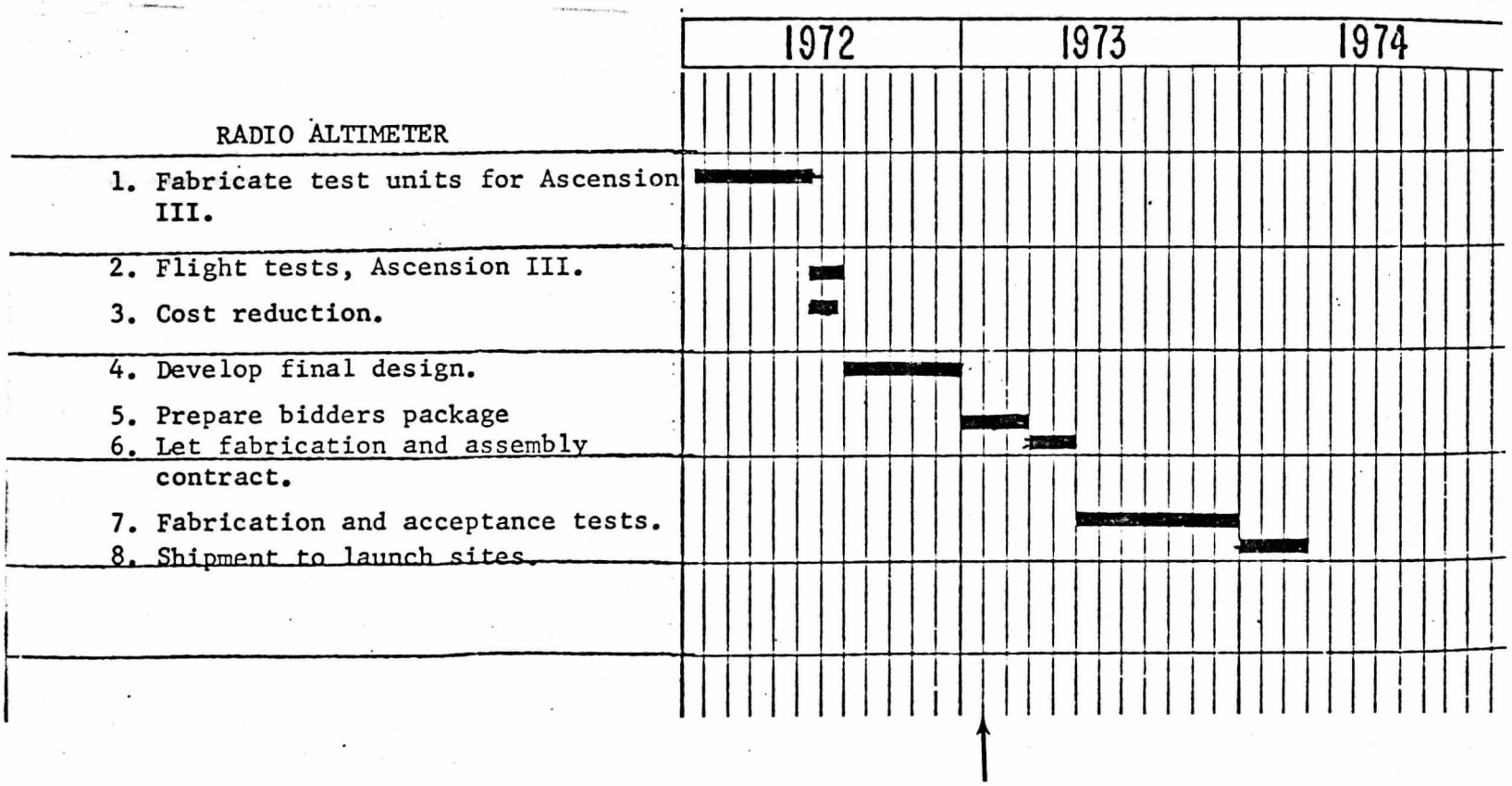

1972
1973
1974
RADIO ALTIMETER
1. Fabricate test units for Ascension III.
2. Flight tests, Ascension III.
3. Cost reduction.
4. Develop final design.
5. Prepare bidders package
6. Let fabrication and assembly contract.
7. Fabrication and acceptance tests.
8. Shipment to launch sites.

TABLE II-8

WEIGHT DISTRIBUTION, POWER REQUIREMENTS, AND APPROXIMATE COST OF FLIGHT TRAIN COMPONENTS

| COMPONENT | WEIGHT (grams) | POWER (watts) RF On | POWER (watts) RF Off | COST ($) |
|---|---|---|---|---|
| Balloon | (3300) | | | 600. |
| Solar Panel | 161 | (2.4) | (2.4) | 258. |
| Antenna | 150 | | | 115. |
| Cutdown | 45 | 0.07 | 0.07 | 68. |
| Data Encoder | 150 | 0.10 | 0.10 | 240. |
| Transmitter/ Oscillator | 200 | 1.40 | 0.60 | 540. |
| Temperature Sensor | 20 | 0.05 | 0.05 | 60. |
| Pressure Sensor | 100 | | 0.10 | 120. |
| Radio Altimeter | 150 | | 0.84 | 245. |
| Foam Packages & Flight Train Rigging | 160 | | | 90. 30. |
| Helium | | | | 20. |
| | 1136 gms | 1.62 | 1.76 | $2,386. |

# Experiments with

# Liquid-Filled Pressure Capsule

## The Problem

Pressure capsules must be designed to withstand sea-level atmospheric pressure even though the capsule is intended for measurement use at low pressures and over a small measurement range. To withstand sea-level pressure without excessively stressing the capsule material it is necessary to use strong (stiff) materials. The stiffness required to withstand sea-level pressure places a limit on the deflection sensitivity of the device. In addition, when the pressure capsule is cycled from a low pressure to a high pressure and then back to the same low pressure, it retains a memory of its high pressure excursion that results in a deflection offset. This offset phenomenon is most often referred to as hysterisis.

## Liquid Stop

A method of preventing a low pressure capsule from being distorted by high surface pressure is to partially fill the capsule with a liquid. The liquid used should be one with a very low vapor pressure at the desired operating temperature. There are several oils designed for use in vacuum pumps that meet this criteria. An example is Dow Corning 704 Silicon oil which has a vapor pressure of $10^{-6}$ mmHg at $+20^{\circ}$C. The amount of liquid placed in the capsule is determined by the maximum pressure that is to be measured. For example if the capsule is to be used for a pressure measurement from 200 mb to lower pressures, the amount of liquid placed in the capsule would be that which fills the capsule when the external pressure is 200 mb. In other words the volume of filling liquid is equal to the internal volume of the capsule when it is being deflected by a 200 mb differential pressure. It is of course important that the liquid be well outgased before filling the capsule so that gas is not introduced into the evacuated capsule. When the capsule is filled in this manner it behaves as a normal capsule for pressures below 200 mb. Pressures above 200 mb compress the capsule against the liquid. Since the liquid is noncompressible, the capsule remains in pressure equilibrium without further deflection. Increased external pressure only increases the

internal hydraulic pressure. Since the capsule cannot be deflected beyond its 200 mb deflection, pressure excursions to much higher pressures have no effect in causing a hysterisis offset.

## Mathematical Model

Equation (1) is a mathematical model of a liquid-filled capsule.

$$P = dK + \frac{M}{do - d} \tag{1}$$

where

P = pressure

d = deflection of the capsule

K = a constant which includes the spring constant of the bellows and the effective area.

do = the deflection where the liquid fills the capsule

M = a constant determined by the small amount of gas remaining in the capsule and the temperature of the gas

The term dK is an approximation of the capsule performance with no liquid in the capsule.

The term $\frac{M}{do - d}$ provides the liquid stop in the mathematical model. This term can be used to experiment with the effect gas inside the capsule. A very small M is equivalent to virtually no gas. It can also be used to experiment with the effect of temperature on pressure measurement. The valve of M is directly proportional to the absolute temperature. If the absolute temperature is doubled, M is doubled. Figure 1 is a family of curves derived from the equation $P = dK + \frac{M}{do - d}$ for values of M between 0 and 1000.

## Experimental Results

Figure 2 is a photograph of the test aparatus that was constructed to experimentally verify the predicted performance of a liquid-filled capsule. The test aparatus was built with a stop-cock through which liquid or gas could be introduced. This allowed experimentation with various values of M and do. Figures 3, 4, and 5 show test results

with different values of M and do. Figure 3 shows the performance with a large gas bubble inside the capsule. Figure 4 shows the results when the residual gas is considerably less. A computation was performed to determine the constants for the test shown in Figure 4. The resulting constants were:

$$K = 13.84$$
$$do = 13.89$$
$$M = 188.46$$

Figure 5 is from experimental data obtained when the gas bubble was small.

Effect of Temperature on Pressure Measurement

A useful exercise is to compute the effect of temperature on the pressure measurement when a small amount of gas is present inside the capsule. To perform this exercise the constants obtained from test 2 (Figure 4) are used. Equation (2) describes the pressure due to gas inside the capsule:

$$Pg = \frac{M}{do - d} \qquad (2)$$

where

$Pg$ = pressure due to gas
$do = 13.89$
$d = 8.5$ (150 mb deflection)
$M_1 = 184.6$ (at $293^{\circ}K$)

$$Pg_1 = \frac{184.6}{13.89 - 8.5} = 34.249 \text{ mb}$$

$$\frac{184.6}{293} = \frac{M}{T}$$

If the temperature is decreased by $10^{\circ}C$

$$\frac{184.6}{293} = \frac{M_2}{283}$$

$$M_2 = 178.3$$

$$Pg_2 = \frac{178.3}{13.89 - 8.5} = 33.080$$

The change in pressure is 34.249 - 33.080 = 1.169 mb per $10^{o}C$ or .1169 mb per $1^{o}C$.

The above computations were for a relatively large gas bubble inside capsule. If the amount of gas were decreased by a factor of 10, the effect of temperature would also be reduced by a factor of 10.

Negative Pressure

Under certain conditions a liquid can support a negative pressure. If this occurred inside the oil-filled capsule the liquid in the capsule would go from compression through zero pressure force into a tension force without the wall of the capsule separating from the liquid. This condition can only occur when there are no gas bubbles present in the liquid, or the system is not subjected to any shocks. The minimum allowable amount of gas present may be determined by the amount required to prevent negative pressure.

Minimum Temperature Constraints

Two oils were used in the experimental tests that were performed. These oils were placed in a temperature chamber and cooled. In both cases the freezing temperature was approximately $-20^{o}C$. The viscosity of the oils decreased rapidly above $-20^{o}C$. It is estimated that the oils would have a sufficiently low viscosity at $-10^{o}C$ to function in a liquid-filled capsule system. No test has been performed to determine if the freezing of the liquid would effect the calibration. It is not known whether a liquid exists that has both a low vapor pressure and a low freezing temperature; or if it is possible to dissolve a solid in the oil and drastically reduce the freezing temperature.

Conclusions

1. A liquid can be used to greatly reduce the hysterisis produced by large pressure excursions.

2. The sensitivity over a low pressure range can be increased,

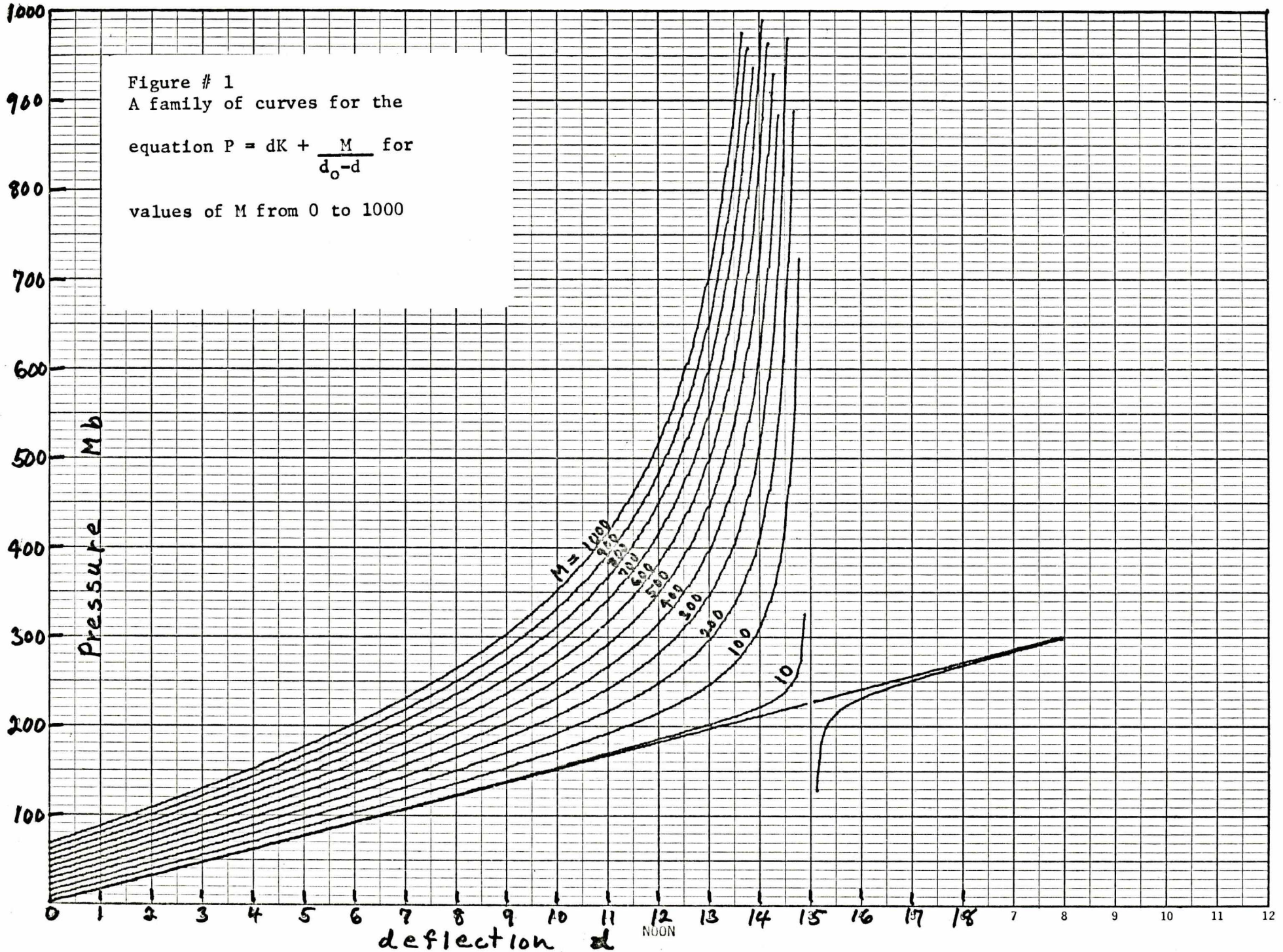
3. Residual gas produces a non-linear pressure versus deflection curve.

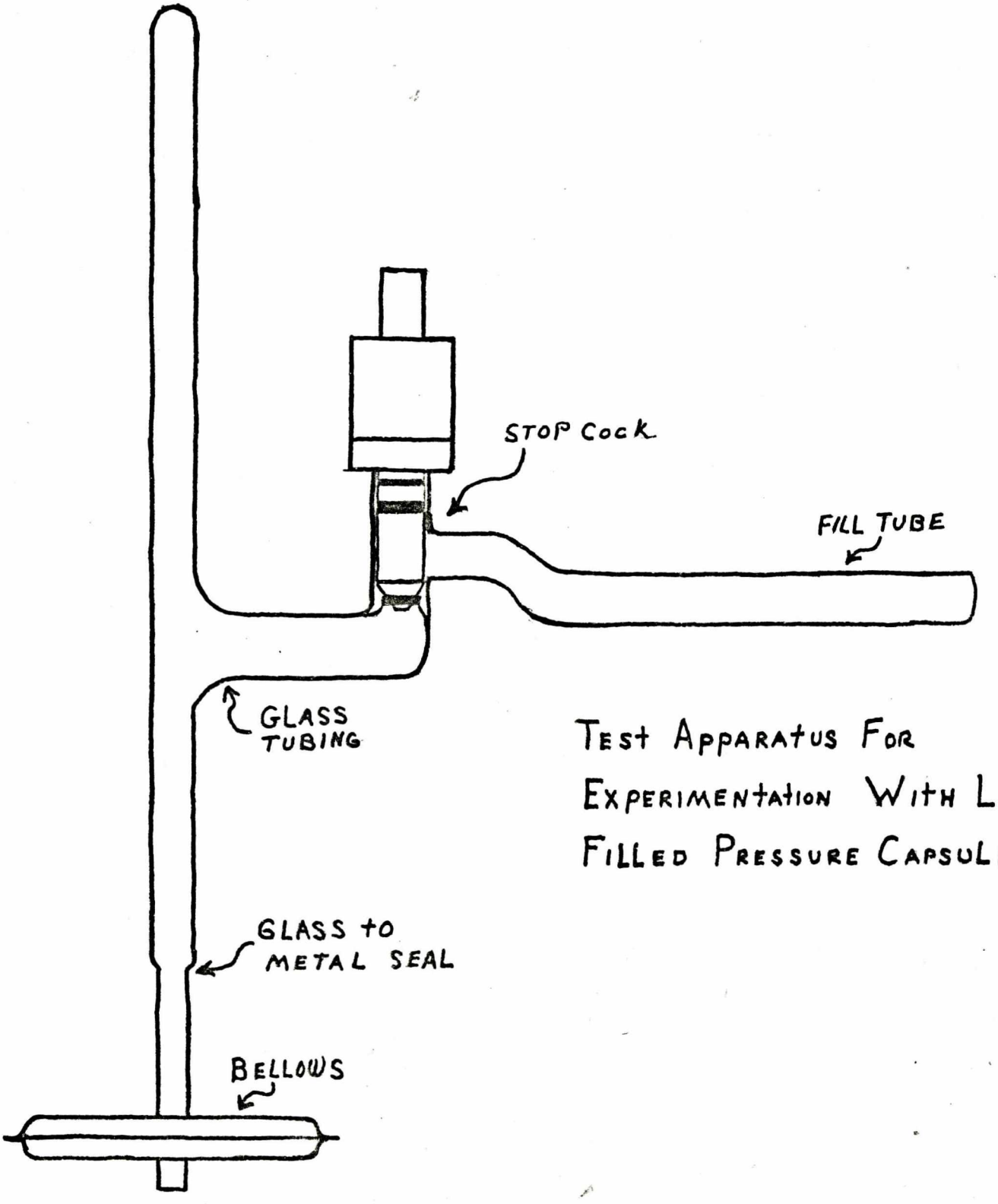
4. Pressure measurement error caused by temperature change is proportional to amount of residual gas. The error can be corrected if the gas temperature is known.

5. Liquids exist that have sufficiently low vapor pressure.

6. Investigations should be made to determine if freezing of the liquid changes the calibration, and the other liquids should be investigated to determine if a more suitable one exists.

K+E 1 DAY BY HOURS
X 100 DIVISIONS
KEUFFEL & ESSER CO.
46 2050
MADE IN U.S.A.






TEST APPARATUS FOR EXPERIMENTATION WITH LIQUID FILLED PRESSURE CAPSULE

FIG # 2

K+E 1 DAY BY HOURS
X 100 DIVISIONS
KEUFFEL & ESSER CO.
46 2050
MADE IN U.S.A.

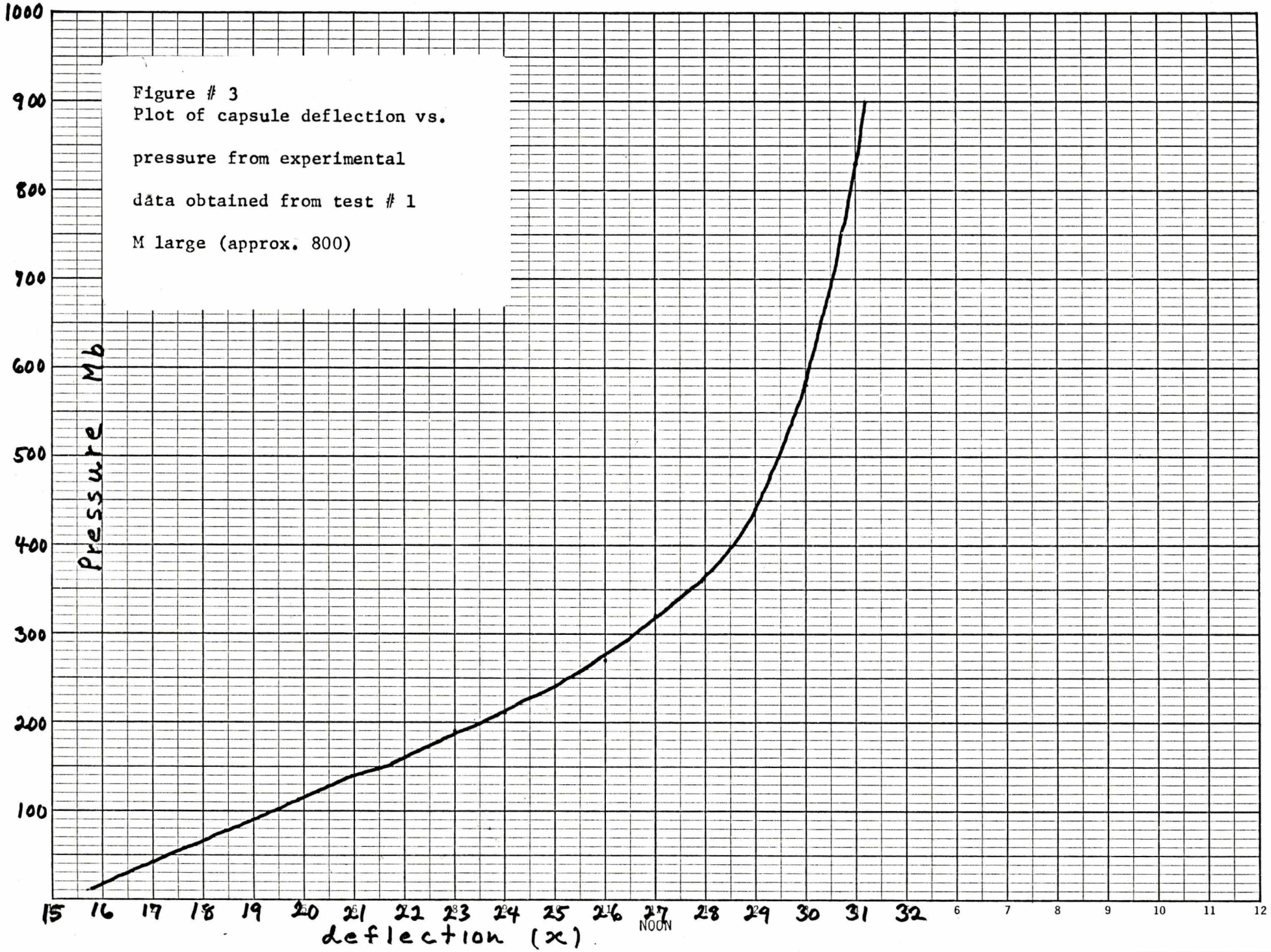



Figure # 3
Plot of capsule deflection vs. pressure from experimental data obtained from test # 1

M large (approx. 800)

K+E 1 DAY BY HOURS X 100 DIVISIONS 46 2050 MADE IN U.S.A.
KEUFFEL & ESSER CO.

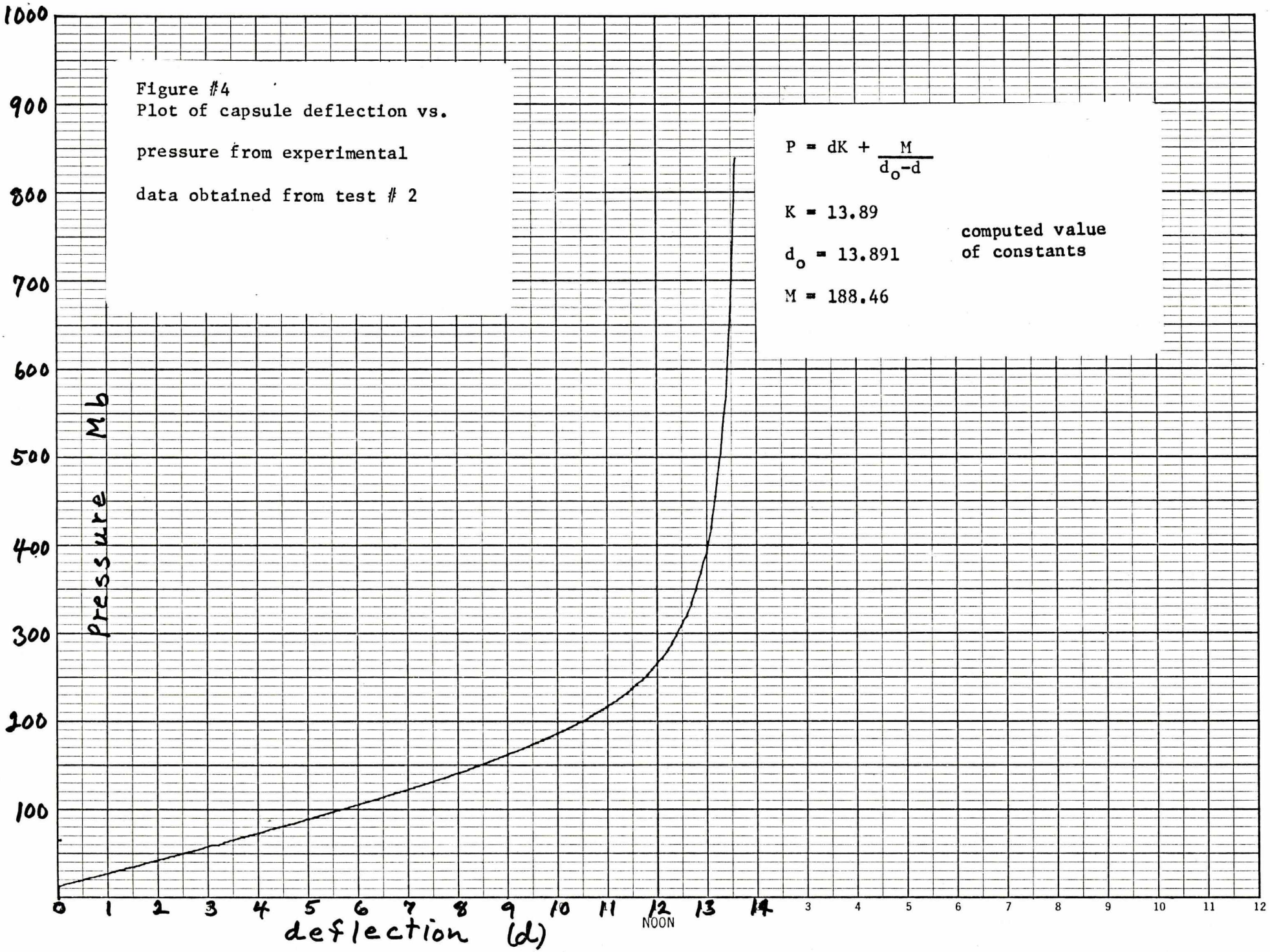



Figure #4
Plot of capsule deflection vs. pressure from experimental data obtained from test # 2

$$P = dK + \frac{M}{d_o - d}$$

computed value of constants

$K = 13.89$

$d_o = 13.891$

$M = 188.46$

K+E 1 DAY BY HOURS X 100 DIVISIONS 46 2050 MADE IN U.S.A.
KEUFFEL & ESSER CO.

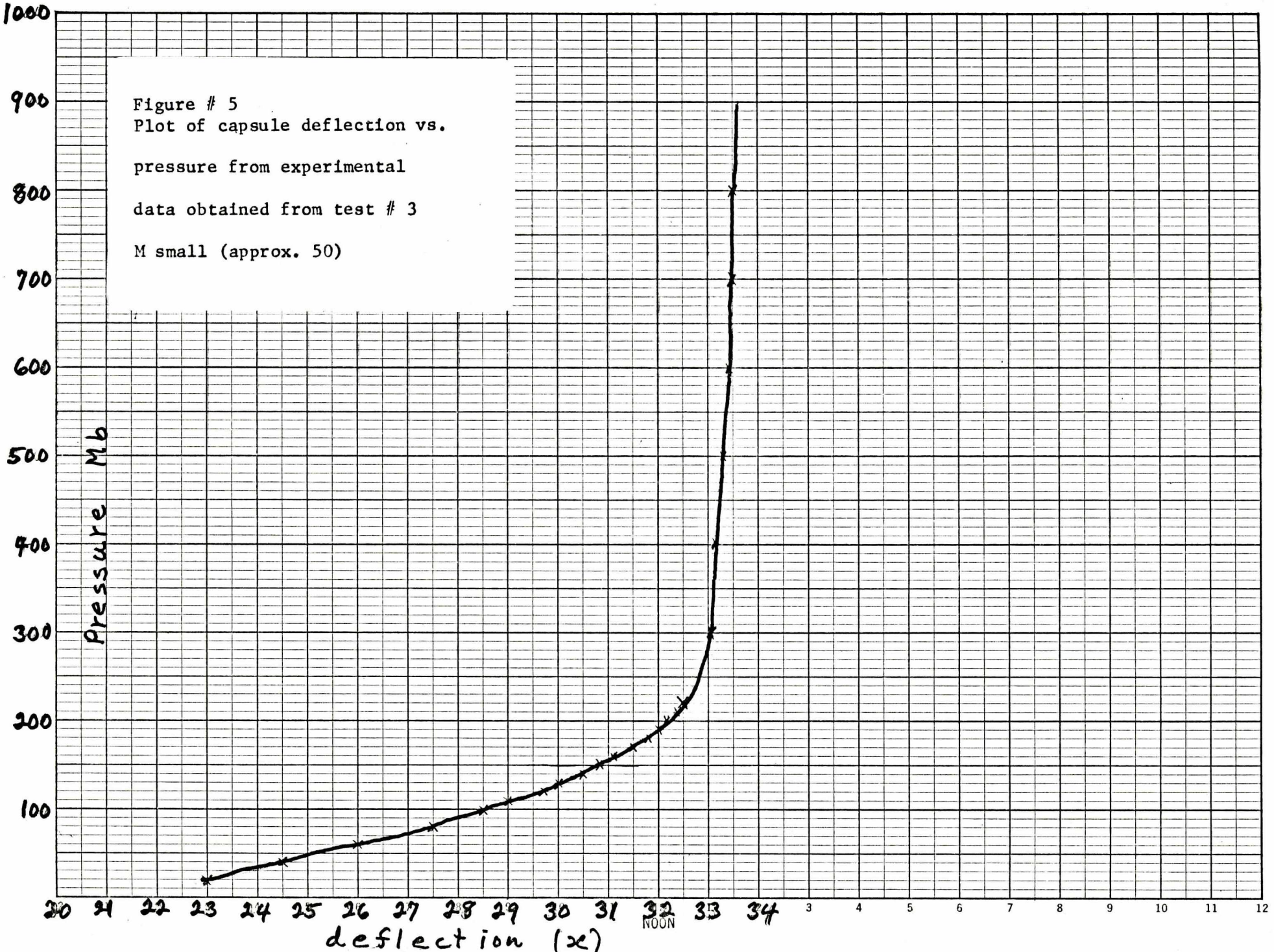



Figure # 5
Plot of capsule deflection vs.

pressure from experimental

data obtained from test # 3

M small (approx. 50)