ANNEX G
To
CRITIQUE OF ALL NASA MARS WEATHER DATA, WITH EMPHASIS ON PRESSURE:
Tavis Transducer Specifications and Test Results (This Annex was updated on 12/2/2018)

This Annex presents data from the NASA Ames Historical Archives and other sources in an attempt to clarify the question of what transducers were available to go to Mars during the Viking1 and 2 plus Pathfinder missions. The initial operating assumption was that Professor James Tillman is correct about 18 mbar Tavis transducers used for Vikings 1 and 2, with a 12 mbar Tavis sensor sent on Pathfinder, but all of them suffered from problems related to dust-jammed air intake tubes and clogged dust filter. However, exactly which sensors were sent to Mars is still an issue. The first entering argument against the 25 mbar sensor it is based on the Alvin Seiff Collection as summed up in Figure 1 below:

I. Viking Project

NATIONAL SPACE SCIENCE DATA CENTER NSSDC.GSFC.NASA.GOV
RIGHT CORNER ACCESS SERVICE MASTER CATALOGUE
ON LEFT SPACE CRAFT VIKING VIKING LANDER OR CLICK ON DATA COLLECTIONS
IMAGING AND METEOROLOGY. SPACE CRAFT LINK IS BETTER.

1. Pressure Sensors

Box 1, Folder 1	Viking Project Pre-Test Report for Investigation to Determine Location of Terminal Descent/Landed Pressure Sensor Orifice, 1971
Box 1, Folder 2	Conrac and Tavis Base Pressure Sensors, Flight Acceptance Test and Calibration Data, (Folder 1 of 2), 1973-1975
Box 1, Folder 3	Conrac and Tavis Base Pressure Sensors, Flight Acceptance Test and Calibration Data, (Folder 2 of 2), 1973-1975
Box 1, Folder 4	Tavis 0-25 millibars Sensors Test Data, Science Testing, (Folder 1 of 2), 1973-1974
Box 1, Folder 5	Tavis 0-25 millibars Sensors Test Data, Science Testing, (Folder 2 of 2), 1973-1974
Box 1, Folder 6	Flight Acceptance Test and Calibration Data. Tavis Pressure Sensors for F.C. A and B and Flight Spare. Tavis' Explanation of Mechanisms. Letters from Specification Sheets, (Folder 1 of 2), 1974-1976
Box 1, Folder 7	Flight Acceptance Test and Calibration Data. Tavis Pressure Sensors for F.C. A and B and Flight Spare. Tavis' Explanation of Mechanisms. Letters from Specification Sheets, (Folder 2 of 2), 1974-1976
Box 2, Folder 1	Viking Entry Science Team Tests of the Parachute Phase Pressure Sensor 0 to 25 millibars Range, 1974
Box 2, Folder 2	Engineering Evaluation Test Report for a 0.1 Absolute Pressure per Square Inch Tavis P-4A Pressure Transducer, 1973
Box 2, Folder 3	Vibrating Diaphragm Pressure Transducer, 1966-1967
Box 2, Folder 4	Evaluation Testing of Tavis 25 millibars Pressure Sensors, 1973
Box 2, Folder 5	Pressure Sensor, Viking Project, (Folder 1 of 2), 1969-1975
Box 2, Folder 6	Pressure Sensor, Viking Project, (Folder 2 of 2), 1969-1975

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Figure 1 to Annex G – Tavis pressure sensors tested according to the Alvin Seiff papers. Data compiled by Adrian, S.P., (n.d.). *Guide to the Alvin Seiff papers*. Retrieved from http://www.oac.cdlib.org/data/13030/08/kt738nd508/files/kt738nd508.pdf

The records on Figure 1 cover the period between 1969 and 1975. Viking 1 launched on August 20, 1975. Viking 2 was launched on September 9, 1975. Note that no sensor listed was for 18 mbar. There are four references to 0-25 mbar sensors, and one reference to a P-4A rated at 0.1 Absolute Pressure per Square Inch (PSIA).

By 25 mbar, it is apparent that this rating is actually a rounded figure that pertains to the Tavis sensor rated at 0.36 PSIA. The 0.36 PSIA figure equals 24.82 mbar. The Tavis CAD for that sensor was shown earlier as Figure 9A in the Basic Report, but for convenience it is shown again below in this Annex as Figure 2.

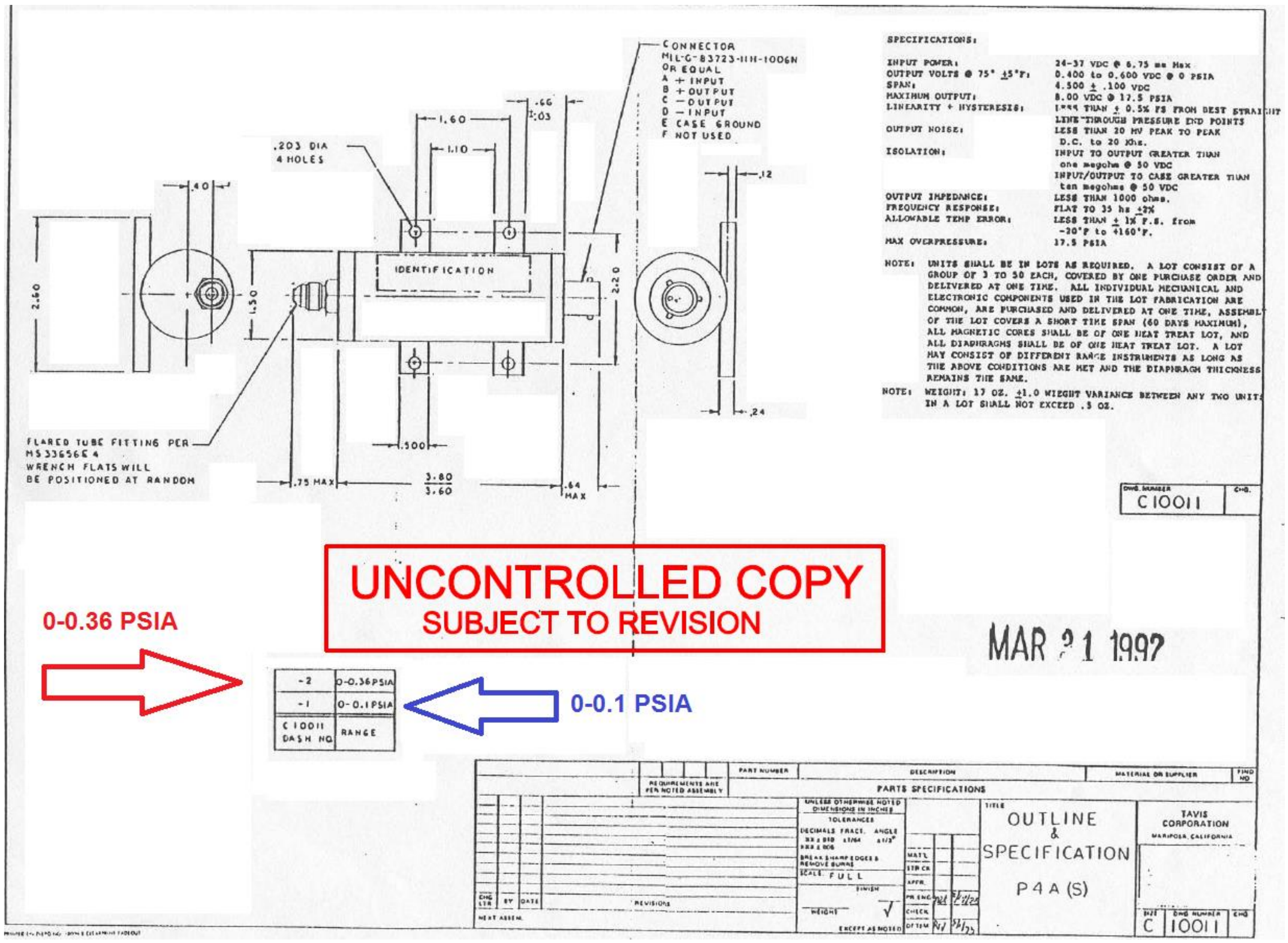

Figure 2 - Adapted from Tavis CAD Diagram 10011. For Vikings Tavis Dash No -2 had a 0.36 PSIA limit (24.82 mbar). However, Tavis Dash No -1 had a 0.1 PSIA limit (6.9 mbar). Source: Personal communication, Tavis Corporation 10/29/2009.

So, the question must be asked, does any NASA document back the 18 mbar figure given the Professor Tillman, the Director of the Viking Computer Facility? The answer is yes. His numbers are supported by the NASA Report TM X-74020, *Evaluation of Viking Lander Barometric Pressure Sensor* (dated March 19877) by Michael Mitchell (hereafter referred to as the Mitchell Report). Its abstract in block 16 is of particular interest. See Figure 3 below:

1. Report No. NASA TM X-74020
2. Government Accession No.
3. Recipient's Catalog No.
4. Title and Subtitle: Evaluation of Viking Lander Barometric Pressure Sensor
5. Report Date: March 1977
6. Performing Organization Code: 1277
7. Author(s): Michael Mitchell
8. Performing Organization Report No.
9. Performing Organization Name and Address: NASA Langley Research Center, Hampton, Virginia 23665
10. Work Unit No. 815-10-00-00-06
11. Contract or Grant No.
12. Sponsoring Agency Name and Address: National Aeronautical and Space Administration, Washington, D.C. 20546
13. Type of Report and Period Covered: Technical Memorandum
14. Sponsoring Agency Code
15. Supplementary Notes
16. Abstract

Two variable reluctance type pressure sensors with a full range of 1.79 x 10^3 N/M^2 (18 mb) were evaluated to determine their performance characteristics related to Viking Mission environment levels. Twelve static calibrations were performed throughout the evaluation over the full range of the sensors using two point contact manometer standards. From the beginning of the evaluation to the end of the evaluation, the zero shift in the two sensors was within 0.5 percent and the sensitivity shift was 0.05 percent. The maximum thermal zero coefficient exhibited by the sensors was 0.032% over the temperature range of -28.89°C to 71.11°C. The evaluation results indicated that the sensors are capable of making high accuracy pressure measurements while being exposed to the conditions mentioned herein.

17. Key Words (Suggested by Author(s)) (STAR category underlined): Viking Pressure Sensor Test; Low Pressure Measurement; Pressure Calibrations; Martian Pressure Measurement
18. Distribution Statement
19. Security Classif. (of this report): Unclassified
20. Security Classif. (of this page): Unclassified
21. No. of Pages: 108
22. Price*: $5.50

*The National Technical Information Service, Springfield, Virginia 22161

Figure 3 – Adapted from NASA Report No. TM X-74020 (the Mitchell Report) published in March 1977. Page 4 of the report specifies that the two sensors tested were P-4 sensors having serial numbers S/N 1583 and S/N 1591.

Page 4 of the Mitchell Report under Test Results states the following about what sensors it examined: “Two Tavis Corp. Model **P-4 sensors**, having serial numbers S/N 1583 and S/N 1591, were chosen to be evaluated using the Viking Mini-Mission format. On **September 23, 1975**, the sensors were connected to the vacuum system and pumped to less than 10^{-1} N/M^2 (10^{-3} mb).” The full report is 110 pages, but what immediately catches the eye is the sensor tested (the P-4) and the date of the tests (starting on September 23, 1975. This testing was thus begun ***after*** both Vikings had already been launched (Viking 1 launched on August 20, 1975, Viking 2 on September 9, 1975). A picture of the P-4 was supplied to me by April Gage, the NASA Ames historian. The photo clearly indicates that the P-4 was rated at 0.2 PSID – see Figure 4. However, the writing on red ink on the document provided by NASA indicates that Model P-4A was purchased!

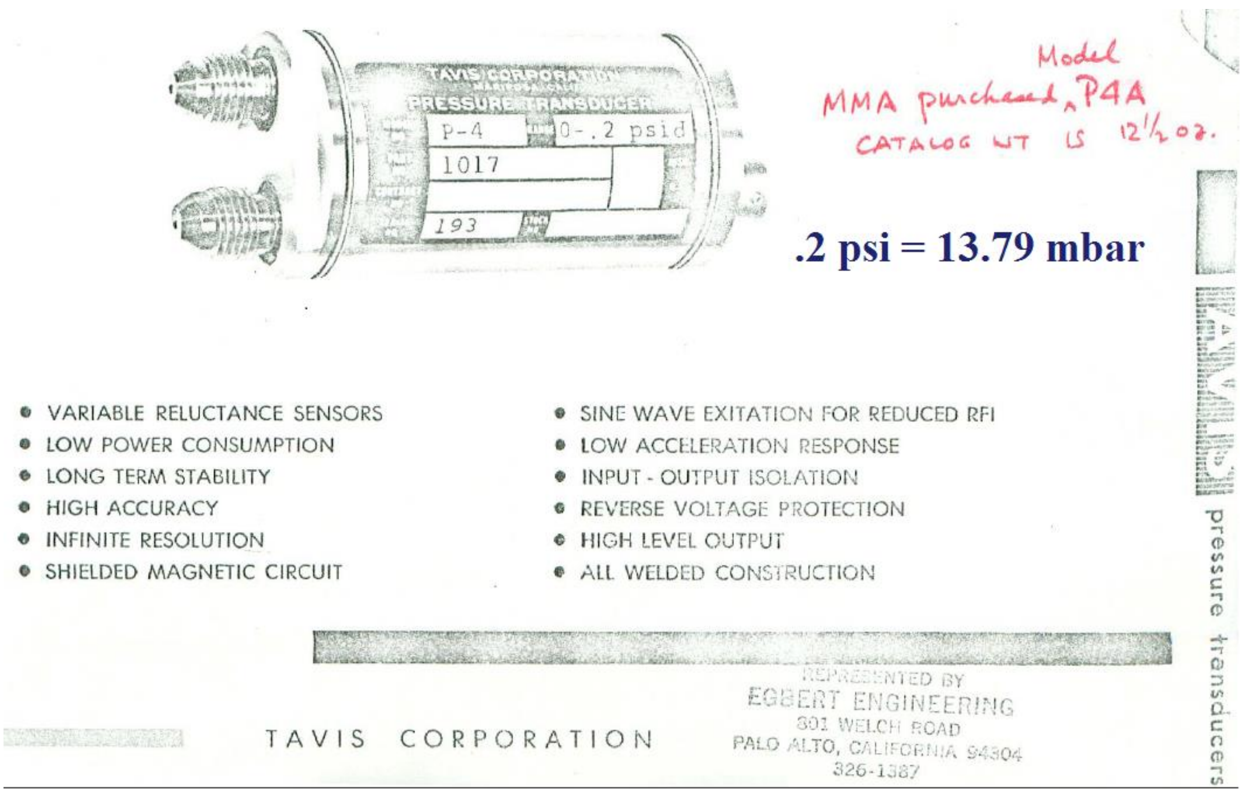

Figure 4 – Photo of the Tavis P-4 pressure sensor, and written indication that a P-4A was ordered. The date of this particular order is not clear.

Does the figure above, or its writing in red, support the 18 mbar (or 17.9 mbar) figure offered earlier in the Mitchell Report? No. The P-4 shown in Figure 4 is clearly labeled as having a range of 0 to 0.2 psid (not psai). What does that mean? Differential pressure measurement is the difference between two unknown pressures. Output is zero when the two pressures are the same, regardless of magnitude. Differential Pressures are notated as "D" (PSID). The magnitude of the common pressure is called "static" or "base" pressure. Differential transducers are usually "wet/wet" construction. This definition is taken from http://www.iprocessmart.com/techsmart/pressure_help.htm. However, if we assume that one side of the sensor feels less than 0.001 mbar, then essentially the sensor tested was capable measuring a difference of up to 0.2 psi. That amount converts to 13.79 mbar, not 17.9 not 18 mbar.

What about the red writing that indicates a P-4A was purchased? There is nothing on the document that indicates the date it was purchased. But what was the capability of the P-4A? See Figure 1. According to the *Guide to the Alvin Seiff papers* (Box 2 Folder 2), it is apparent that there was an "Engineering Evaluation Test Report for 0.1 Absolute Pressure per Square Inch Tavis P-4A Transducer, 1973." That is 0.1 PSIA. This amount equates to 6.9 mbar, still not close to 18 mbar. I have pressed Professor Tillman hard on these issues now for most of 2010. On November 25, 2010, he finally sent me an e-mail with two attachments. I was surprised to find that the 110-page Mitchell Report was the first of them. We had debated that report back in May 2010 when he first informed me about the radioisotope thermoelectric heaters (RTGs) that were supposed to protect the transducers from external temperatures that were clearly much colder than the -28.89° C tested (see block 16 – the Abstract on the Mitchell Report shown on Figure 3 above) in the very late tests that occurred well after both Vikings were on their way to Mars.

How much colder than -28.89° C was it on Mars? See Appendix 1 to Annex D of this report. It shows that the temperature reported from the surface of the planet on VL-1 Sol in the 0.22 time-bin was -85.76° C (the first temperature recorded at time-bin 0.02 on VL-1 Sol 1 was -78.28° C (in summer at Ls 97.196).

For Viking 2 the first temperature recorded was also at night. It was -72.05° C in the .06 time-bin (VL-2 Sol 1.06), but by Sol 1.18 it was down to -80.26° C (still in the summer). So the obvious question here is, *Just how fast did the RTGs kick on and was it fast enough to prevent damage to the transducer*? To date, all requests from Professor Tillman for specific information about RTG operations have gone unanswered. It is important to know (1) how fast they began to operate and (2) what triggered their operation – temperature outside, inside, or a simple timer?

The minimum temperature recorded in Viking 1's first day (-85.76° C, or -122.368 °F) was 54.78°C (98.766° F) colder than what was tested for in the Mitchell Report. And yet the Vikings were both subjected to far colder temperatures as they moved from the summer temperatures felt on landing to the winter lows. For Viking 1 the coldest temperature felt (in its tropical location) was -95.96°C (-140.728°F). For Viking 2 the temperature got as low as -121.01°C (-185.18 °F).

Figure 11 in this Annex (the Tavis Corporation's transducer ordering information) yields a -53.89 °C minimum temperature allowed, but that is still not as cold as what was felt by either Viking immediately upon landing.

Now aside from the issue of whether the temperature was too cold for the transducers, there is the issue of the red writing on Figure 4. It is not at all clear as to why NASA would want a transducer that is limited to 0.1 psia/6.9 mbar. As was shown on Table 5 of the Basic Report of my report, Mariner 4 only attempted two pressures readings – and one of them was between 7 and 9 mbar. Mariners 6 and 7 attempted a total of four readings, and two of them ranged from 6.9 to 7.3 mbar. Finally, Mariner 9 saw 10.3 mbar. All of these measurements were in NASA hands well before the Vikings were launched. And yet, the second of two attachments sent to me by Professor Tillman on November 25, 2010 seems to allude to the P-4A (7 mbar) as is seen on Figure 5:

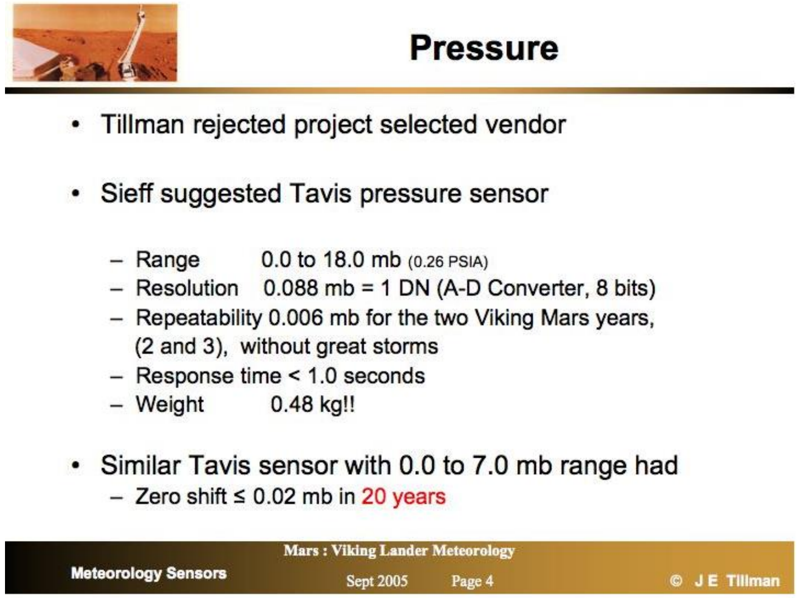

Figure 5 – Transducer Selection Slide by Professor James E. Tillman

While Professor Tillman has not yet answered questions about the mechanism for RTG operation/timing, the above slide was extremely important for three reasons:

(1) It shows that in September 2005, long before my study began in 2009, he was quoting the pressure range of a Sieff (presumably Alvin *Seiff* mentioned earlier in conjunction with Figure 1) suggested Tavis pressure sensor rated at 0.0 to 18.0 mb (mbar). The 0.26 PSIA figure actually converts to 17.926 mbar.

(2) It provides the resolution of the sensor as 0.088 mbar. That matches what I found and discussed in conjunction with Section 2.4.1 of my Basic Report (The issue of Viking pressure reports and digitization).

(3) It mentions a *similar* Tavis sensor with 0.0 to 7.0 mbar range with zero shift ≤ 0.02 mbar in 20 years. This is almost certainly the P-4A. It is not clear from the slide as to which project selected vendor was rejected by Professor Tillman, but since the slide dates from before the launch of the Phoenix, it may be a reference to the Vaisala transducer selected for that mission. Since the Vaisala was limited to 12 mbar, and since Viking 2 measured at least 10.72 mbar on its Sol 277.34, it would not make sense to back a sensor that could only see 12 mbar.

For the benefit of those who want to investigate the issue of possible confusion with respect to Tavis sensors and their capabilities, this Annex also includes the Tavis CAD for the Pathfinder mission. Shown in the Basic Report as my Figure 9B, it is labeled as Figure 6A in this Annex. Finally, the three pages of the Tavis specifications and parts order information received from the NASA Ames historical office are included as Figures 7, 10 and 11. Note that on Figure 10, for the Tavis P-4, the minimum pressure range is 0.1 psi and the maximum is 100 psi. Again, 0.1 psi is 6.8945 mbar, while **100 psi is 6,894.5** mbar! Thus one Tavis transducer with the same model number could apparently be tweaked by the producer to produce results that differed by three orders of magnitude. This is a thousand fold potential source of error. In looking at Figure 6A, there were clearly two entirely different pressures given – 0.174 PSIA (12mbar) and 15 PSIA (1,034 mbar. Martian weather simply does not match the lower pressure range offered. The controversy continues with Insight. See Figure 6B.

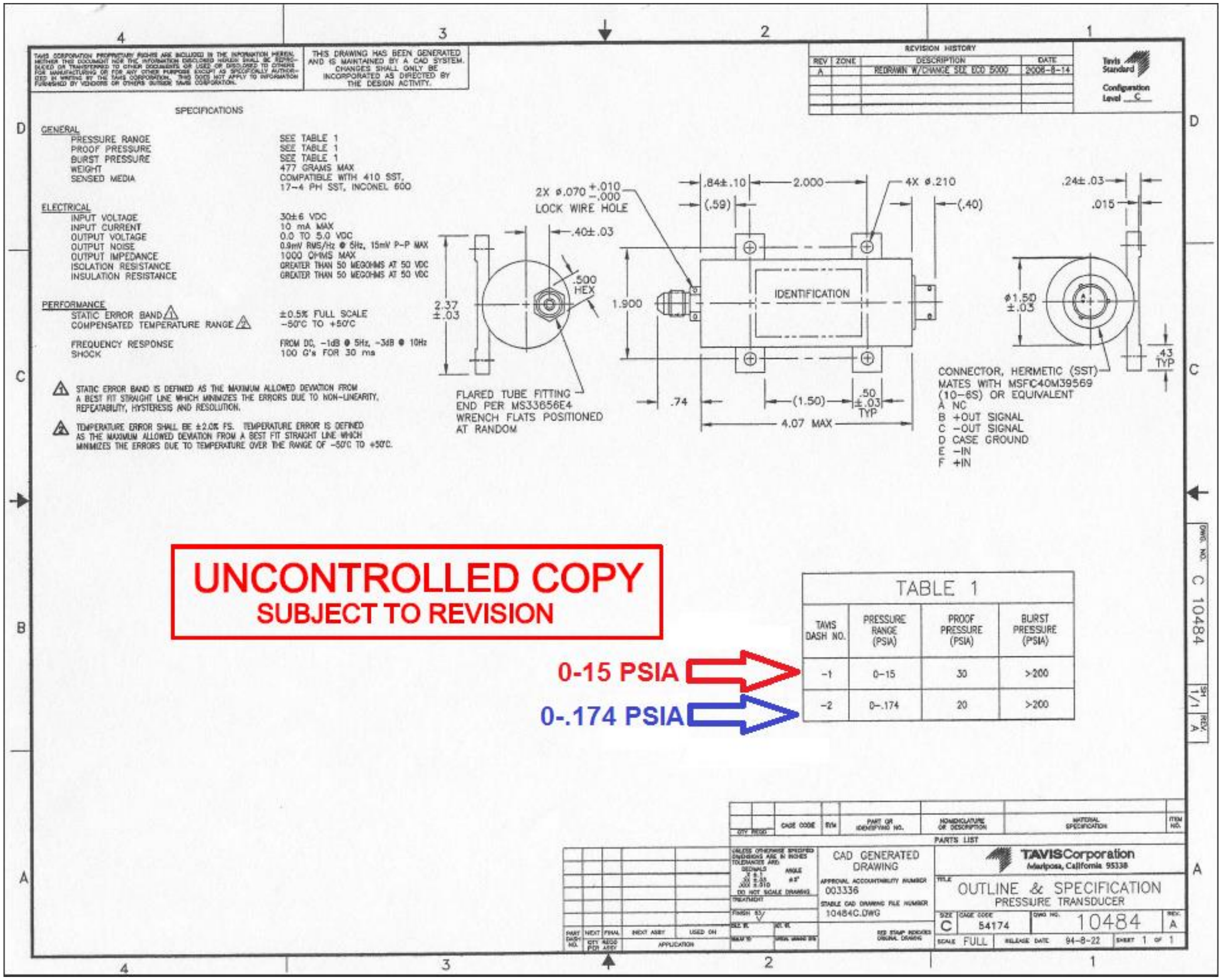

Figure 6A – Adapted from Tavis CAD Diagram 10484. For Mars Pathfinder Tavis Dash No -2 had a 0.174 PSIA limit (12 mbar). However, Pathfinder Tavis Dash No -1 had a 15 PSIA limit (1,034 mbar). Source: Personal communication, Tavis Corporation 10/29/2009.

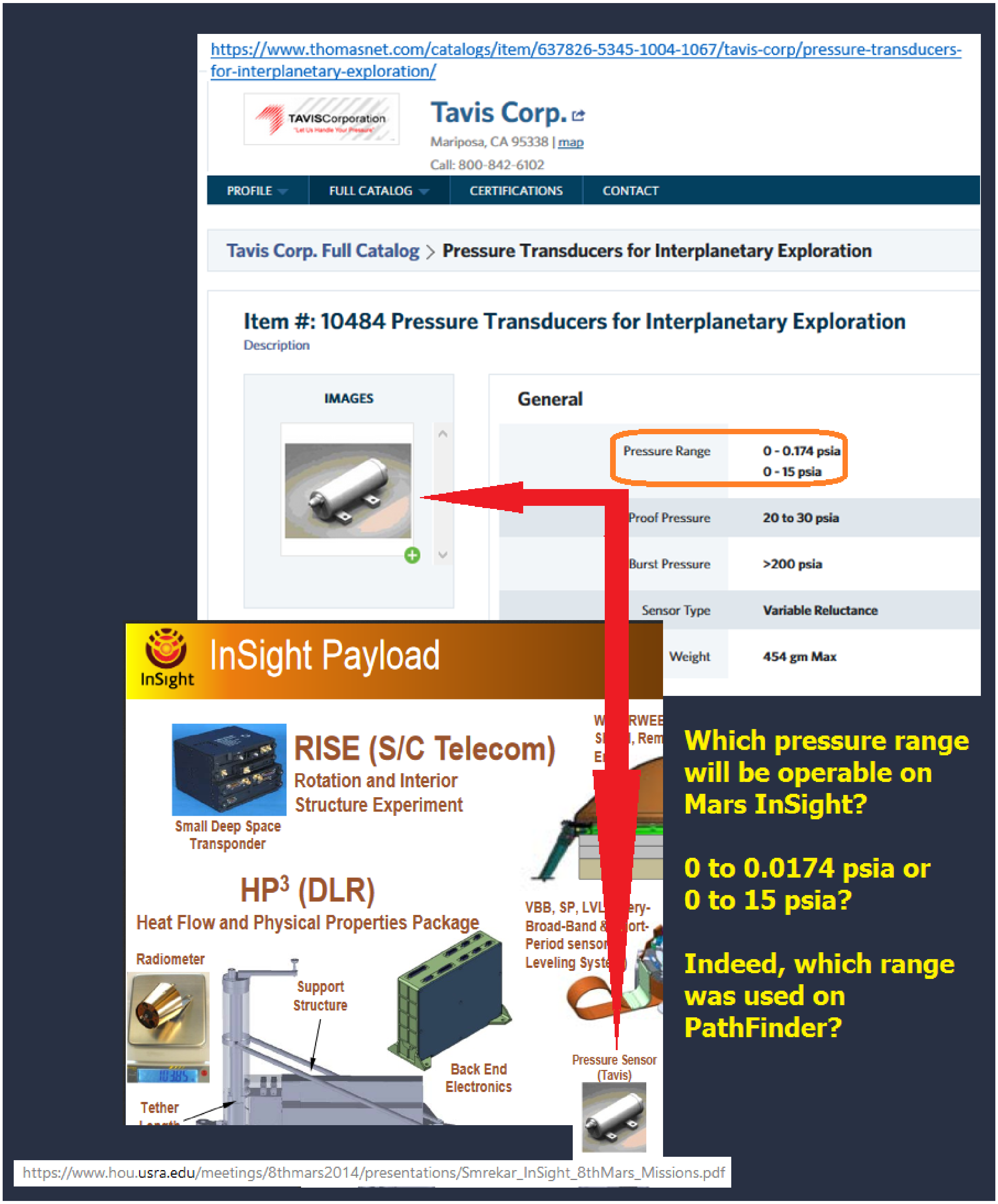

Figure 6B – The controversy over the pressure range of the Tavis pressure transducer continues with the pressure sensor chosen for Mars InSight. Tavis did not, at least initially, answer the question about whether InSight can measure pressure up to 15 psia (1,230 mbar) or 0.174psia (12 mbar). In particular, can the same sensor change ranges with radio command or flip of a switch?

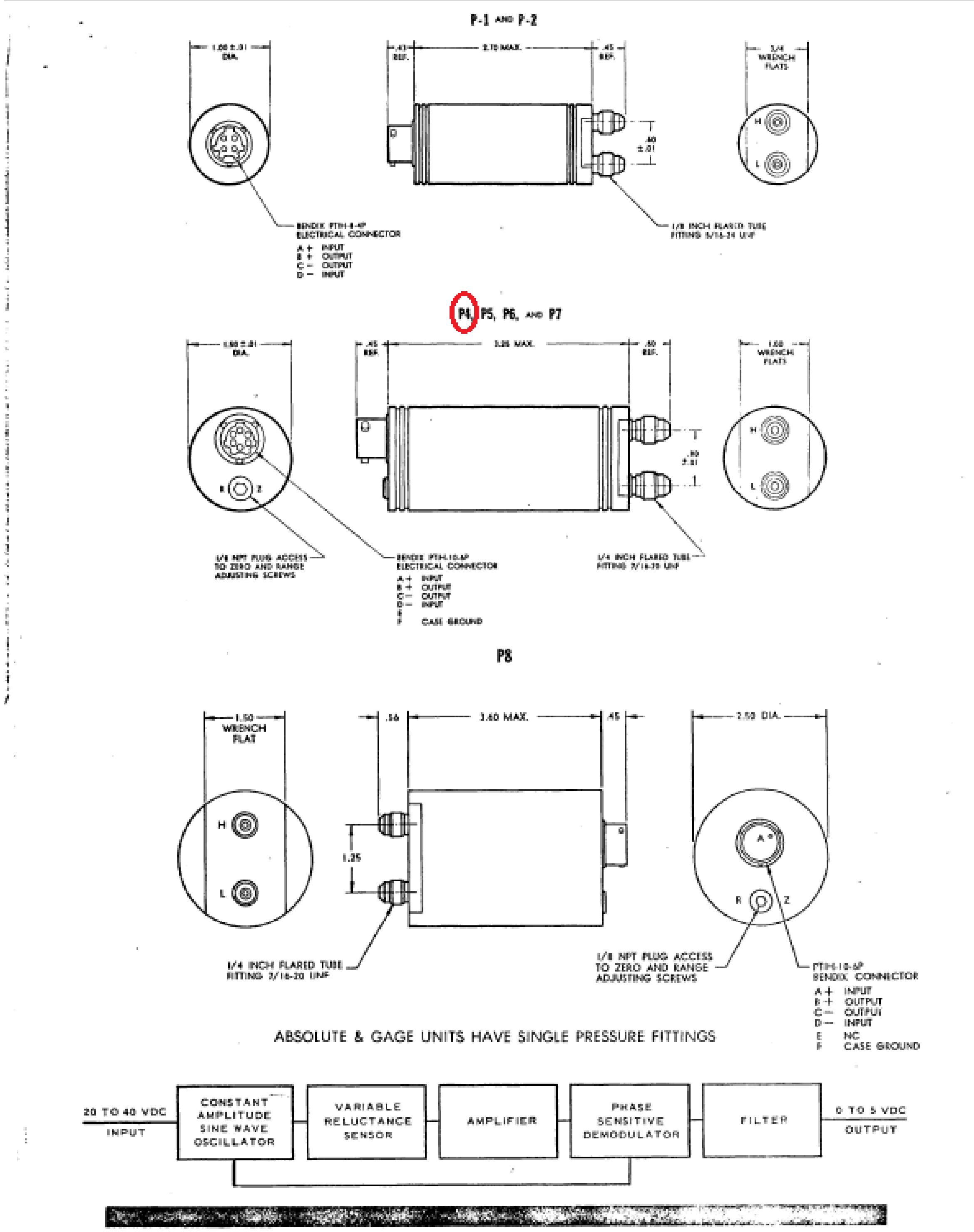

Figure 7 - Design diagrams for Tavis transducers (Models P-1, P-2, P-4, P-5, P-6, P-7 and P-8).

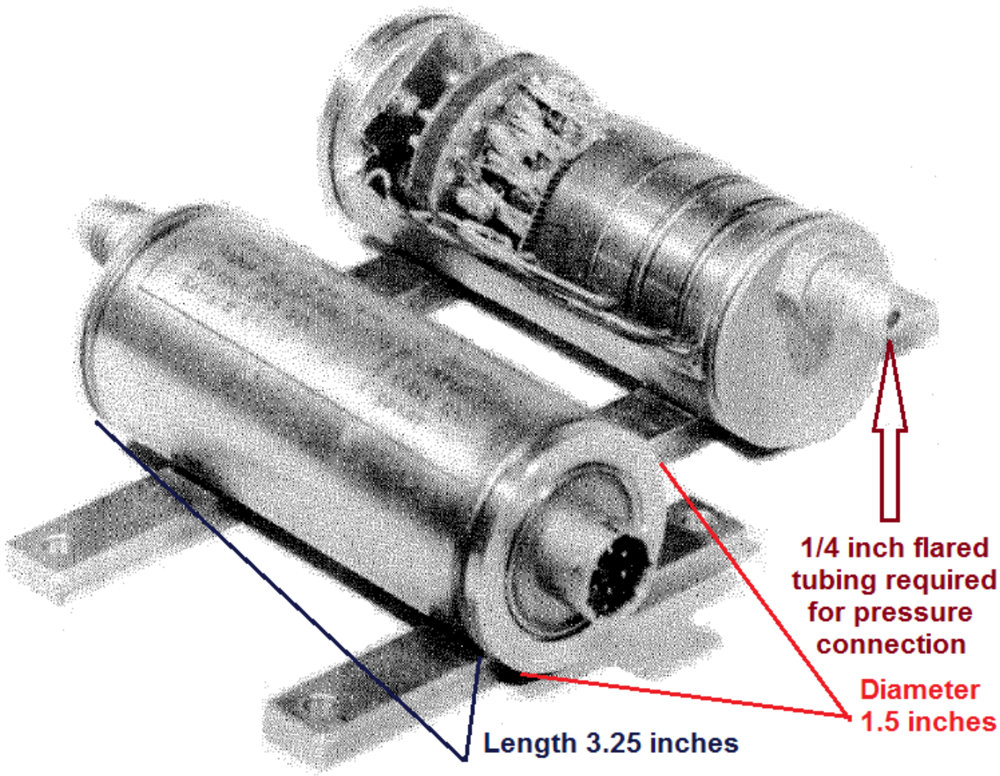

Figure 8 – Tavis P-4 Transducers (S/N 1583 and S/N 1591) used for test of Viking pressures sensors after the launch of the two Vikings. NASA Report TM X-74020 (the Mitchell Report).

Figure 9 – Relative sizes of dust filters used for Tavis and Vaisala pressure transducers.

TABLE OF CHARACTERISTICS

MODEL NUMBER P—		1	2	4	5	6	7	8
MINIMUM PRESSURE RANGE (PSI) FS		1	100	0.1	0.1	100	100	0.01
DIAPHRAGM NATURAL FREQUENCY (Hz)		3.5K	12K	2K	2K	10K	10K	500
ACCELERATION RESPONSE (%FS/g)		.03	.003	.3	.3	.007	.007	3
MAXIMUM PRESSURE RANGE (PSI)		100	2500	100	100	2500	2500	100
DIAPHRAGM NATURAL FREQUENCY (Hz)		12K	47K	10K	10K	37K	37K	7K
ACCELERATION RESPONSE (%FS/g)		.003	.0005	.007	.007	.0007	.0007	.015
PRESSURE INPUT OPTIONS		GAGE ABSOLUTE DIFFERENTIAL	GAGE ABSOLUTE	GAGE ABSOLUTE DIFFERENTIAL	GAGE ABSOLUTE DIFFERENTIAL	GAGE ABSOLUTE	GAGE ABSOLUTE	GAGE ABSOLUTE DIFFERENTIAL
ADJUSTMENTS	RANGE	NONE	NONE	± 2% F.S.	± 50% F.S.	± 2% F.S.	± 50% F.S.	± 2% F.S.
	ZERO				± 2.5V		± 2.5V	
MAGNETIC SHIELDING		SINGLE	SINGLE	SINGLE	SINGLE	SINGLE	SINGLE	DOUBLE
PRESSURE FITTINGS	Flared Tube	⅛	⅛	¼	¼	¼	¼	¼
DIAMETER (Inches)		1	1	1.5	1.5	1.5	1.5	2.5
LENGTH (Inches) (1)		2.7	2.7	3.25	3.25	3.25	3.25	3.60
WEIGHT (Ounces)		5	5	12.5	12.5	12.5	12.5	40
SPECIAL FEATURES AVAILABLE								
HIGH OVERPRESSURE		X	X	X	X	X	X	X
OUTPUT VOLTAGE CLAMP		X	X	X	X	X	X	X
CALIBRATE SIGNAL				X	X	X	X	X
CORROSION APPLICATION		X	X	X	X	X	X	X
SPECIAL TEMPERATURE COMPENSATION		X	X	X	X	X	X	X
OFFSET ZERO		X	X	X	X	X	X	X

(1) Low pressure ABSOLUTE instruments are slightly longer.

Figure 10 -Table of Characteristics of Tavis transducers (Models P-1, P-2, P-4, P-5, P-6, P-7 & P-8).

-65 °F = -53.89 °C

General Specifications

Static error band	±½% Full Scale	(note 1)
Input voltage	20 to 40 VDC	
Input current	6 ma. nominal value	
Output	0-5 VDC ±50 mv at end points	
Output impedance	50 — 100 ohms	
Output noise	15 mv - maximum	
Frequency response (Electronic circuit)	Flat ±5% Full Scale to 500 Hz	
Insulation resistance	100 megohms min. at 100 VDC	
Maximum overpressure	20 psi or twice rated pressure whichever is greater	
Temperature range	−65° F to +165° F	(note 1)
Temperature error	Less than ±2% F.S.	(note 1)
Vibration	35 g's peak to 2000 Hz	(note 2)
Shock	1000 g's for 11 ms	(note 2)
Materials in contact with pressure media	410 stainless steel and inconel 600	(note 3)
Other	Meets MIL-E-5272C for humidity sand and dust, altitude, rain, salt spray, immersion and fungus. Pressure ports must be sealed during test.	

1. Closer tolerances and high temperature operation may be supplied. Consult the factory for your special requirements.
2. Adjustable zero and range - 20 g's (potentiometer limit)
3. Instruments for corrosive applications are made of 17-4 or 17-7 PH and Inconel 600.

Our continuing product improvement program may cause changes in specifications without notice.

Accessories Available

- AC line to 28 VDC Power Converter - Model 1020
- Meter Readout Systems
- Mating Electrical Connectors
- Electrical Cables
- Mating Pressure Fittings
- Pressure Tubing
- Mounting Brackets

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326-1387

Ordering Information

- Order by Model Number - Pressure Range - Specify Absolute, Gage, or Differential pressure measurement. ie: P-1, 0-15 psia - or - P-1, ±1.0 psid
- All Tavis transducers can be supplied for corrosive media applications. Materials used for this purpose are inconel, 17-4 PH, and 17-7 PH stainless steels. Model numbers of corrosion resistant pressure transducers are the same as the standard models - plus one hundred. Thus, a P-104 is a corrosion resistant P-4.
- Specify Options and Accessories required.
- Your Purchase Order should include:
  - Complete "Charge to" and "Ship to" information.
  - Method of shipment

  Without specific instructions, your order will be shipped "Best Way", insured.
- FOB: Mariposa, California 95338
- Terms: ½ of 1% 10 days, net 30 days.

U.S. PATENT NO. 3,562,687 OTHER U.S. AND FOREIGN PATENTS PENDING

TAVIS CORPORATION
BOOTJACK ROAD — MARIPOSA, CALIFORNIA 95338
(209) 966-2182

2.5K/10-71

Figure 11 – Tavis Transducer purchasing information. Note that the minimum temperature allowed (-65 °F, or -53.89 °C) is not nearly as cold as what was experienced immediately upon landing (in the summer) on Mars. For Viking 1 the first temperature reported was -78.28° C (Ls 97.196), and for Viking 2 it was -72.05° C at Ls 118.102. Both landers experienced even colder temperatures on their first night on Mars (-85.76°C for Viking 1 and -80.26°C for Viking 2). The temperature limits given are for all Tavis transducers, although higher (but not lower) temperature operation parts were available.

In the Mitchell Report under a section entitled *Cruise Environment* and in conjunction with its Figure 20 there are a number of inconsistencies, typos and problems. The two Tavis Model P-4 pressure sensors tested were S/N 1591 and S/N 1583. The sensors are shown on Figure 8. The Abstract states that these tests were conducted just after the Vikings launched "to determine their performance characteristics related to Viking Mission environment levels."

The document states that:

> *On the 9th day, S/N 1591 and S/N 1583 experienced a drop in* ***zero output voltage*** *of 8 mV and 41 mV, respectively, due to a sudden drop and recovery of approximately 67°C. This temperature drop was due to a temporary malfunction in the thermal environment chamber which dropped the temperature to approximately -51° C in one hour. Figure 20 shows a more detailed account of this incident.*

The Mitchell report's Figure 20 is colorized and relabeled as this Annex's Figure 12. There are numerous issues raised by the above report quotation. First, it seems odd that two sensors, experiencing identical drops in temperature, would have such different voltage drops. Forty-one mV is over 5 times greater than 8. Note that this was during the cruise stage with very low pressure 0.1 N/m^2 (0.001 mbar). Next, the -51ºC temperature is lower than the -28.89ºC temperature specified for the test.

Looking at Figure 12, the top graph Y axis is labeled SENSOR OUTPUT (VOLTS). S/N 1591 started with about 0.49 VOLTS. As the temperature drop ensued, the voltage climbed (according to the graph) to about 0.54 VOLTS and then fell to about 0.41 VOLTs. So, overall, it fell from 0.49 to 0.41, a drop of 0.08 – but not mV unless the y Axis is labeled wrong. It probably should read a drop of 0.049 to 0.041. So there is an apparent one order of one magnitude in error here someplace. Is the error on the write up, or on the graph?

S/N 1583 started with about 0.53 VOLTS. We'll ignore the decimal place for now as it's already addressed in the previous paragraph. As the temperature drop ensued, the voltage climbed (according to the graph) to about 0.61 VOLTS and then fell to about 0.45 VOLTs. So, overall, it fell from 0.53 to 0.45, a drop of 0.08 volts. This does not line up well with the drop of 41 mV as specified in the write up. It looks like the person generating the graph might have confused the minimum voltage there of 0.41 (or, really, 0.041) for sensor 1591 with the drop in voltage for sensor 1583.

Finally, the difference in voltage AFTER the temperature climbed back up to almost the right temperature was only about one sixth of what it was before the temperature drop. What might this indicate? Perhaps after the Viking Tavis pressure sensors experienced the REAL cold temperature on Mars, they would spit out essentially identical, but meaningless pressure readings. In-other-words, they were ruined. The area in red on Figure 11 represents the difference in mV between the two sensors tested. Figure 12 illustrates why it is important to understand how fast the RTGs started heating and maintaining uniform temperatures after landings occurred. To understand how small the Tavis and Vaisala dust filters were, see Figure 9.

Added to the above question about the Viking Tavis sensors and the affects of low temperature on them is the fact that during Mars Pathfinder pre-launch calibration of its Tavis transducer, both the flight and flight spare pressure sensors were inadvertently exposed to temperatures 30 K below their design limits (see Annex H and http://starbrite.jpl.nasa.gov/pds/viewInstrumentProfile.jsp?INSTRUMENT_ID=ASIMET&INSTRUMENT_HOST_ID=MPFL).

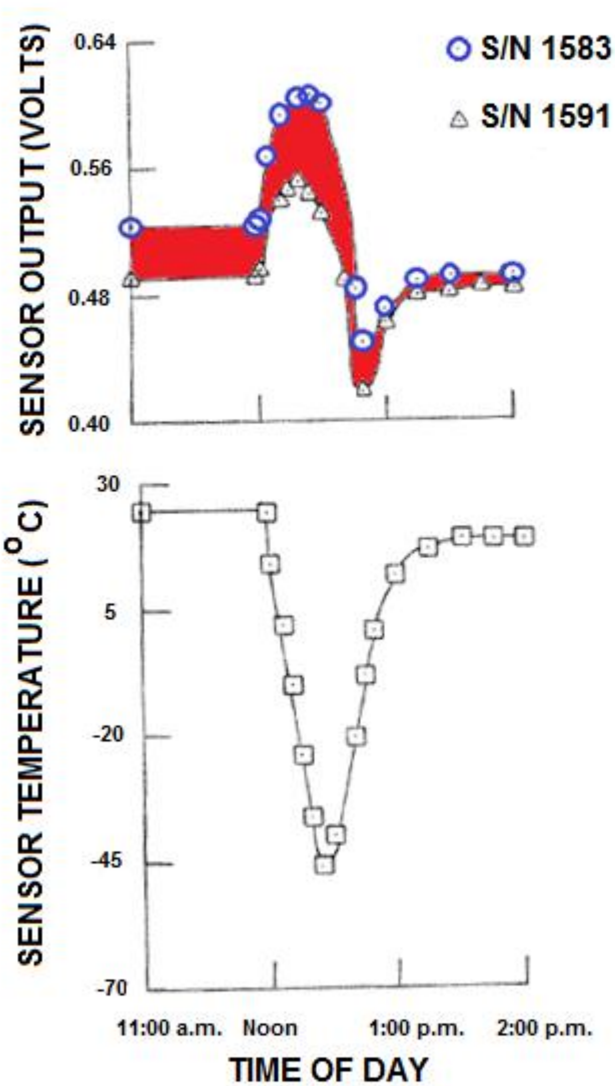

Figure 12 – Temperature Malfunction During (Viking) Cruise Environment. Adapted from Figure 20 in NASA Report TM X-74020 (the Mitchell Report).