Telltale Calibration Report

Version 7

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1 Document log:

21/5 2007	Initial release	Draft composed of the documents in \\VAGROD\hpg\TT_new\analysis\Report which are gathered here in a single document.
25/5/2007	1. corrected edition	File collected on \\FLETTE\ Documents and Settings\flette\Desktop\Speciale \Reports
29/6/2007	Called draft and distributed to ASTG as a pdf file.	
23/1/2008	Added user manual, notes on TiltImages and dynamics	
31/3/2008 version 3	Added notes on compliance with requirements (chapter 11), and more small changes.	
11/4/2008 version 4_draft	Added much more detailed description of error contributions based on discussions with Deborah and Scott. Small additions to the Mirror calibration section	File accepted by Scott and Deborah
10/11/2008 version 5	Changed to version 5, change monitoring removed and put to letter size and sent to Thomas Stein as pdf (HPG)	
1/12/2008 version 6	Added more in-depth introduction	
6/2/2009 version 7	Added Appendix (chapter 13)	

Content

2 Introduction

2.1 The Telltale

The Telltale wind indicator is a mechanical anemometer designed to operate on the Martian surface as part of the meteorological package on the NASA Phoenix lander. It consists of a lightweight cylinder suspended by Kevlar fibers and is deflected under the action of wind. Imaging of the Telltale deflection allows the wind speed and direction to be quantified and image blur caused by its oscillations provides information about wind turbulence. The Telltale will primarily support surface operations by documenting the wind conditions to improve the efficiency of sample delivery to instruments on the lander deck. During the latter stages of the mission the Telltale investigation will focus on meteorological studies.

2.2 Calibration report

This is the seventh version of the Telltale calibration report. At this stage there are several known shortcomings:

1) Not all wind tunnel data has been analyzed, especially the data recorded under 45° rotation are causing problems. As this data will unlikely change the results obtained, they will probably not be used.
2) Tilt Images are still in the process of being analyzed. This analysis is done with the tools being developed for landing operations (see section 12), that consequently are changing.

The main conclusion here is a model that can be applied with the appropriate set of parameters to determine deflections on the surface of Mars and the tools necessary to extract the needed parameters from the images.

New versions of this report are expected when people ask for them, and the one produced before landing will be called final.

2.3 Notes on nomenclature

There has been some misunderstanding in what actually is called the "Telltale". In this report, the "Telltale" is always the active part of the instrument, consisting of the Kapton tube and Kevlar threads (see Fig. 1). When referring to the whole instrument, we use the term "Telltale Assembly" or "Telltale Experiment".

3 Tilt Measurements

3.1 Log

File (folders)	Where	Description
tilt2.pro tilt3.pro	C:\IDL\tilt on \\FLETTE	IDL source code used for all
070329_b14#1analysis.xls	C:\Desktop\Speciale\Tilt on \\FLETTE	Excel folder used for analysis
b14_1analysis_4.xls	C:\hpg\TT_new\analysis\Tilt on \\VAGROD	Should be the last Excel analysis file
Telltale_addin.xla	C:\Desktop\Speciale\Analyse on \\FLETTE	Excel addin file, which contains the functions used in analysis

3.2 Introduction

The aim of the tilt measurements is manifold. First, one needs to determine the path of the Telltale, or the average position of the Kapton part relative to an origin of a coordination system for further analysis. The tip of the screw has been selected as the origin of the coordination system, and all variables are taken relative to that.

Second, a coordinate system is found which is better suited for describing the movement of the Telltale. This coordinate system is also used to calculate the stiffness of the Kevlar fibers.

3.3 Data

The Tilt data consists of images taken of the Telltale attached to a screw and tilted at an angle θ' perpendicular to the direction of the camera. This angle is defined positive in the case illustrated in Fig. 1.
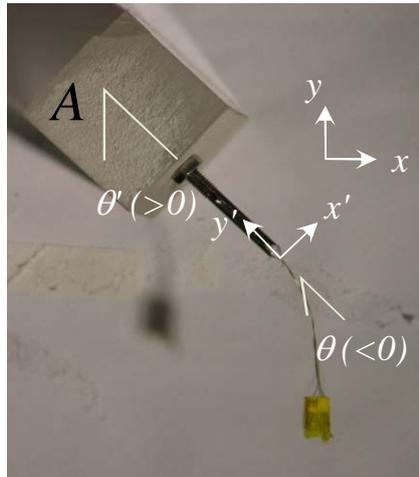
Fig. 1: Definition of the tilt angles; θ' is here positive while θ is negative. Also shown are the directions in the two coordinate systems made use of in the data reduction. The angle θ is defined from the direction of the Kevlar screw towards the Kapton part of the Telltale from an effective hanging point (x_0', y_0') that is found in the analysis.

The data is taken for different orientations φ of the screw as defined in Fig. 2.
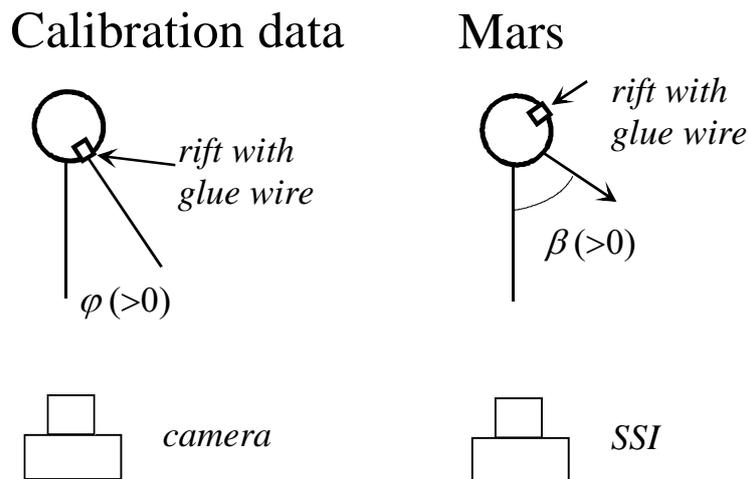
Fig. 2: (Left) Definition of the orientation of the screw for $\theta = 0°$ in the calibration data. The angle φ is here positive. (Right) Definition of the β angle on Mars.

The angle φ is used to catalog our calibration data and results, and can be related to the directions of interest in Mars data. Here one should note, that we record a property of the Telltale in directions $\varphi + 90^\circ$ ($\theta > 0$) and $\varphi - 90^\circ$ ($\theta < 0$). If one observes the Telltale under the angle β on Mars, this should be related to the observation directions φ as:

$$\varphi = 219.2^\circ - \beta, \qquad \text{for } \theta > 0$$

And

$$\varphi = 39.2^o - \beta, \qquad \text{for } \theta < 0$$

For each orientation of φ, of the order of 40 images were taken for different tilt angles θ'. The convention used was to start at high θ' ($\sim\pi/2$), move to negative θ' ($\sim-\pi/2$) and then back again.

The scale of the images (mm/px) was determined by making use of the known size of the Telltale holder (width = 24.79 mm, height = 25.12 mm) marked *A* in Fig. 1.

The raw data is stored under …\Tilt\b14#1\o<φ> on various hard drives containing the raw data from the Telltale calibration. In some cases, additional datasets exists, and these are labeled with a "b".

3.4 Data reduction

The pictures were analyzed with IDL routines in tilt2.pro and tilt3.pro which run a number of tasks/subroutines described below. The original data consists of images taken of the Telltale holder with the Telltale and screw fastened to it as seen in Fig. 1.

The first task is to determine the position of the screw tip in each picture by zooming in on the screw and using the mouse to choose the five points in the screw indicated in Fig. 3. Going counterclockwise the designations are Top Left (TL), Bottom Left (BL), Tip (of screw), Bottom Right (BR) and Top Right (TR).
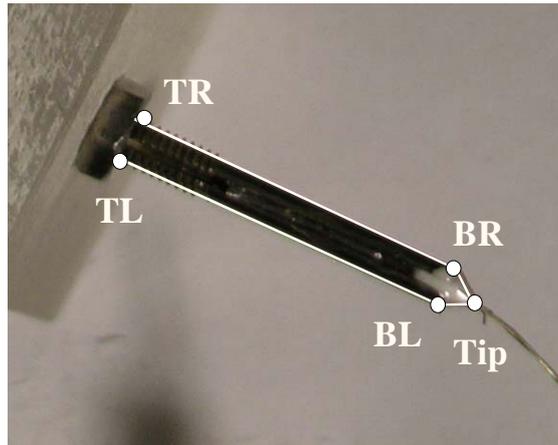
Fig. 3: Blow-up of Fig. 1. The points to be chosen are designated by white points.

For each image, the screw's angle, θ', with respect to vertical is determined from the vectors going from the top point to the bottom point on either side of the screw. The final angle is the average of the angles between vertical and the vectors from the right and left side respectively.

To determine the position of the Kapton part of the Telltale a box is centered on the Telltale in the first picture in a series of tilt pictures as seen in Fig. 4. The average background intensity, B_{ave}, is calculated from the three sides that do not include the Kevlar threads, *i.e.* the left, right and bottom side. B_{ave} is subtracted from the picture within the box thus giving the background zero intensity and ensuring that only the Telltale and the Kevlar thread has a non-zero intensity. The calculations are performed in the blue color only.
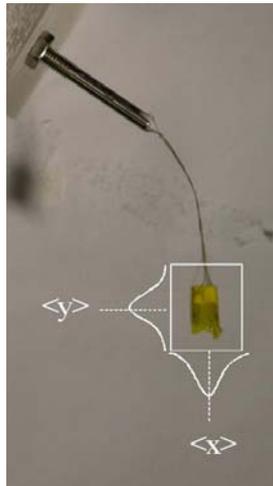
Fig. 4: An example of how the box should be placed in the Tilt pictures. The curves indicate the weighted averages in x and y, showing the final positions of <x> and <y>.

To obtain the (x, y) coordinates of the Telltale in the image, a weighted average of the intensities is calculated by summing the intensities by columns in the x-direction and rows in the y-direction, multiply by the column or row number and dividing by the summed intensity.

This approach was chosen since the uneven shape of the Telltale makes it impossible to choose corners as done with the screw.

For subsequent pictures in the dataset, the user chooses the center point for the box, which should coincide with the center of the Telltale. IDL runs the calculations and the coordinates obtained for a dataset of pictures is written to …\Tilt\o<φ>\ o<φ>(b).txt. This file is subsequently written to an Excel file for further analysis.

3.5 Analysis

3.5.1 Path of the Telltale

It turned out that it was possible to describe the position of the Kapton part in a simple way in the (x', y') coordinate system defined in Fig. 1. All possible positions of the Kapton part of the Telltale can be described on a circle with origin at (x'_0, y'_0) and radius R. This furthermore allows us to determine the position of the Telltale with a single parameter θ defined as the angle relative to the y' axis as illustrated in Fig. 5. The angle θ is positive counter-clockwise from the y' axis.
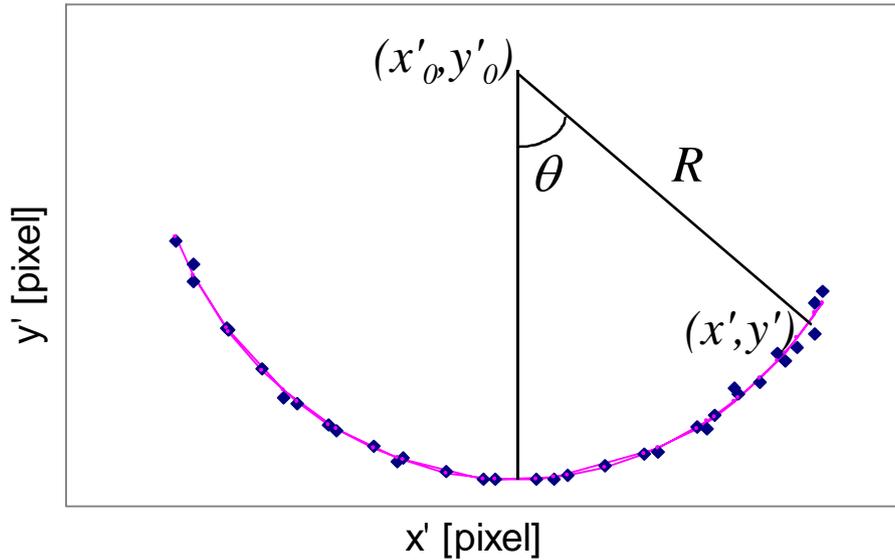
Fig. 5: Definitions of quantities used in the analysis of Tilt data. The angle θ as illustrated in the figure is positive.

The circle of radius R has a centre in the point (x'_0, y'_0). The angle θ will be used to determine deflection or position of the Telltale. It is possible to define this angle in different ways, but the following convention has been applied in all cases:

θ is the angle from the y' axis to the position of the Kapton part of the Telltale, with the origin at (x'_0, y'_0), positive in the counter-clockwise direction.

3.5.2 Origin of the coordination system

From each dataset (same φ), we find the x_0', y_0' and R in pixel coordinates. The length of the Telltale $L = R + y_0'$ should be a constant if the scale of the images is the same. We needed to scale the series (in mm/pixels) since there was a small movement of the camera due to replacement of memory cards and batteries. This scale was found by using the Telltale holder but is not as accurate as the scale found by using the calculated values of L. By scaling the L values we find the average distance of L in mm, and in the end used that value to scale each dataset. We find the mean L distance to be 28.1(2) mm.

In regard to the x_0' parameter, if it is observed under a specific orientation φ, it is also possible to imagine that this observation is made from the behind under $\varphi +180^{\circ}$, but then the value $-x_0'$ is observed. Fig. 6 shows the value of x_0' as a function of orientation, where this feature has been used.
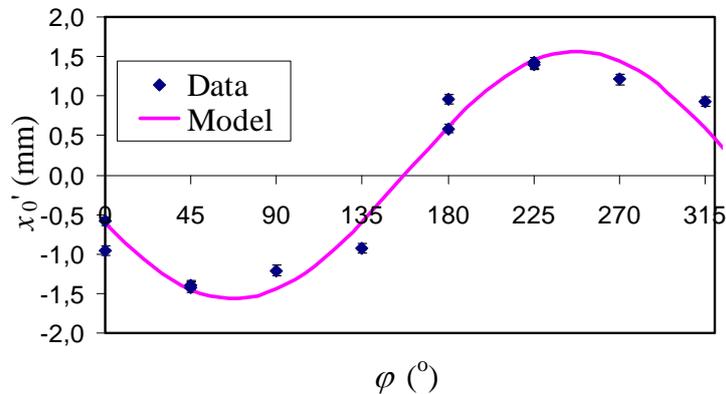
Fig. 6: x_0' as a function of orientation φ. The error bars do not take into consideration errors in determination of the screw tip, and must be underestimated.

This data has been analyzed in terms of a sine function $x_0' = A \cdot \sin(\varphi - \varphi_0)$ that simulates how this parameter should vary upon orientation. The results are $A = 1.6(1)$ mm and $\varphi_0 = 157(4)^o$. This can be viewed as the Telltale is shifted 1.6(1) mm in the direction given by $\beta = -28(4)^o$. We would thereby expect the Telltale to be shifted -0.73 ± 0.13 mm as viewed by the SSI.

The variation in R is shown in Fig. 7 in the same way, except that the sign is the same regardless of the Telltale being viewed under φ or $\varphi + 180°$.
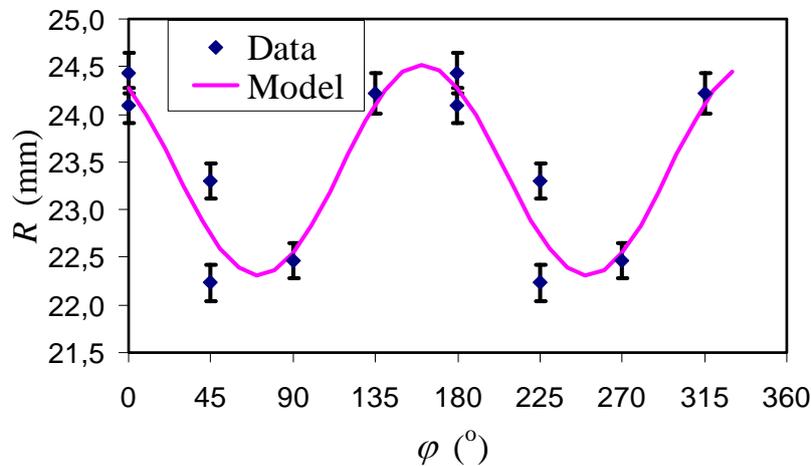
Fig. 7: R as a function of orientation φ.

The data has been simulated using a sin square function $R = R_0 + A \cdot \sin^2(\varphi - \varphi_0)$ and we find $A = 2.2(3)$ mm, $\varphi_0 = 70(4)^o$ and $R_0 = 22.3(2)$ mm. This means that there is an axis where the R is greatest, and/or smallest. The greater radius is at $\varphi = 70(4)^o \pm 90^o$, and the small radius perpendicular to that. Relative to the SSI, the short axis will be at will be at $\beta = -31(4)^o$ and $149(4)^o$ and the greater axis at $\beta = 59(4)^o$ and $-121(4)^o$.

The variation in y_0' is bound by the variation in R, and not presented here as such.

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3.5.3 Mass density integrals

Before we can calculate the Kevlar Stiffness, an introduction to the mass density integrals that enter the energy equations has to be made. They are defined as

$$\rho^{(i)} = \int l^i \rho(l) dl$$

Where $\rho(l)$ is the density along the length of the Telltale. From the construction data this is known with reasonable accuracy.

Table 1: Mass densities of the Telltale determined from construction data.

Part	Length (mm)	Mass density (mg/mm)
Kevlar fibers	24.14	0.04498
Kapton + glue	2.4	4.542
Kapton	4.58	0.205

90% of the mass is situated in the gluing of the Kevlar to the Kapton. The length here is significantly different from the length L above, found to be 28.1(2) mm. However, the centre of the Kapton part is at 27.63 mm, which is in fair agreement with the above. For constant levels of ρ_i and l_i, the mass integrals can easily be evaluated as:

$$\rho^{(1)} = \sum_{i=1}^{3} \frac{1}{2}\rho_i (l_i^2 - l_{i-1}^2)$$

And

$$\rho^{(2)} = \sum_{i=1}^{3} \frac{1}{2}\rho_i (l_i^3 - l_{i-1}^3)$$

using the parameters given in Table 2.

Table 2: Parameters for the F014 Telltale

No.	l (mm)	ρ (mg/mm)
0	0	N/A
1	R-3.49 (mm)	0.04498
2	R-1.09 (mm)	4.542
3	R+3.49 (mm)	0.205

The Excel function "MI(i as integer, R as double)" in the Telltale_addin.xla workbook add-in, calculates the mass integral $\rho^{(i)}$ for the F014 Telltale in SI units.

3.5.4 Stiffness constant

To avoid confusion, the parameters involved are shown in Fig. 8.
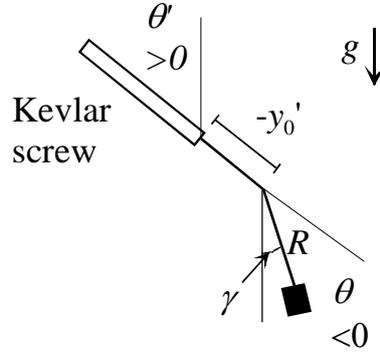
Fig. 8: Definitions relevant to the calculation of stiffness constants.

For an infinitely stiff Telltale, θ will always be zero. For an infinitely soft Telltale, the Kapton part will hang in the direction of gravity and $\theta = -\theta'$. The gravitational energy of the Telltale is described by:

$$U_G = \rho^{(1)}(\varphi) \cdot g \cdot (1 - \cos(\theta' + \theta))$$

using the sign rules represented in Fig. 8. The mass integral $\rho^{(1)}$ is taken from the (x_0', y_0') position, which depends on the orientation φ. The Kevlar fibres try to make the angle θ as small as possible. This contribution can be represented by a power expansion.

$$U_K = A_K^{(0)} \mid \theta \mid + A_K^{(1)} \theta^2 + A_K^{(2)} \mid \theta^3 \mid + A_K^{(3)} \theta^4 + \ldots$$

The first term will not contribute to a force and the energy in minimized when

$$0 = \frac{d(U_K + U_G)}{d\theta} = 2A_K^{(1)}\theta + 3A_K^{(2)}\theta \mid \theta \mid + 4A_K^{(3)}\theta^3 + \rho^{(1)}(\varphi) \cdot g \cdot \sin(\theta' + \theta)$$

Rewriting this we have:

$$0 = a_1\theta + a_2\theta \mid \theta \mid + a_3\theta^3 + \sin(\theta' + \theta)$$

which has to be solved numerically in terms of three parameters a_1, a_2 and a_3 that are:

$$a_1 = \frac{2A_K^{(1)}}{\rho^{(1)}(\varphi) \cdot g}$$

$$a_2 = \frac{3A_K^{(2)}}{\rho^{(1)}(\varphi) \cdot g}$$

$$a_3 = \frac{4A_K^{(3)}}{\rho^{(1)}(\varphi) \cdot g}$$

The hysteresis is added directly to the model and end points removed from the analysis. In the analysis performed here, two of the three a_i terms should be enough to describe the Telltale in details, thus a_2 has been set to zero. The graphs used are drawn relative to the $\gamma = \theta + \theta'$ angle that gives a better information on the quality of the fit.

As an example Fig. 9 shows a typical hysteresis curve obtained.
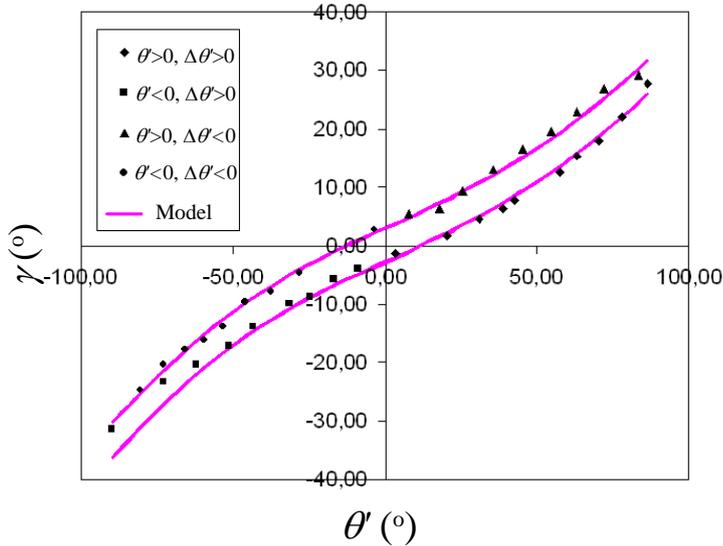
Fig. 9: Example of a hysteresis curve for the Telltale, obtained under $\varphi = 135^{\text{o}}$.

Before it is possible to determine the parameters from the analysis, the mass density integrals have to be solved.

It turns out that the variation predicted in this formula, is not enough to show the variation in a1. This can be understood in terms of the physics of the fibers. Under angles that show additional stiffness, the radius of motion is correspondingly shorten, and this is exactly what is observed.
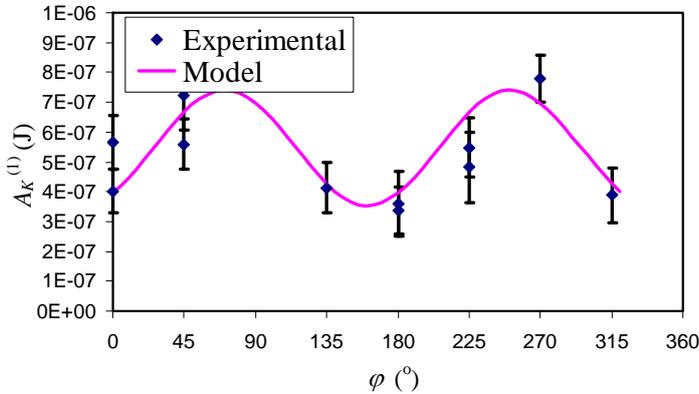
Fig. 10: The value of $A_K^{(1)}$ as function of orientation angle.

The data has been analyzed in terms of a model $A_K^{(1)} = \alpha \cdot \sin^2(\varphi - \varphi_0) + \beta$ where the parameters for α = $(3.8 \pm 0.7) \cdot 10^{-7}$ J and $\beta = (3.5 \pm 0.4) \cdot 10^{-7}$ J where found and φ_0 was restricted to follow the dependence for the radius. As one can expect, the stiffness is greatest where the circular motion has the shortest radii.

The value of $A_K^{(3)}$ shows no significant dependence on orientation, and a general value was found to be $A_K^{(3)} = (1.40 \pm 0.36) \cdot 10^{-7}$ J.

3.5.5 Updated Stiffness Constant

It turns out from the wind tunnel experiments that the variation in stiffness along the length of the Telltale is not as prominent as suggested by the Tilt measurement data. If the 90° point is dropped from the analysis, it turns out that a much smoother result is obtained, that is in much better correspondence with the wind tunnel measurements. As a part of this, the data was re-examined and refitted. The model for the Stiffness constant was altered slightly to

$$A_K^{(1)} = \alpha \cdot \left(\sin^2(\varphi - \varphi_0) - \tfrac{1}{2}\right) + \beta$$

to easier express what it the combination between average and variation.

Table 3: Updated stiffness constants based on wind tunnel data.

Parameter\Method	All points	Excluding 45° (and 270°)
α	$(3.86 \pm 0.71) \cdot 10^{-7}$ J.	$(2.40 \pm 0.91) \cdot 10^{-7}$ J.
β	$(5.47 \pm 0.25) \cdot 10^{-7}$ J.	$(4.98 \pm 0.32) \cdot 10^{-7}$ J.

In the version 1 calibration data, we apply $\alpha = 1.50 \cdot 10^{-7}$ J. In this re-examination the value for the other $A_K^{(3)} = (8.5 \pm 4.2) \cdot 10^{-8}$ J

3.6 Summary of Excel functions

Table 4 shows the Excel functions defined in this section:

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Table 4: Excel function defined in this section.

Function	Excel function	Comments
$\rho^{(i)}(R)$	MI(I,R)	R given in mm, Output in SI untits
$A_K^{(i)}$	AkMod(Phi)	Phi given in degrees, output in SI units (J)
$R(\varphi)$	Rmod(Phi)	Phi given in degrees, output in mm.

3.7 Summary and Conclusions

The Telltale selected for Flight is considerably different from earlier versions of Telltales, especially in the respect that it is not a relatively long tube. This has meant that the results are worked out differently than was described in the Telltale CDR and earlier versions of the CCC report. The main findings are listed below:

a. The path of the telltale can be described well using a circular motion around an effective binding point that varies in height with orientation
b. With this binding point shifted away from the screw direction, there is no offset in the position of the Telltale.
c. The stiffness can be described as a power law, that leads to some complications with respect to the formulas
d. Excel functions with the main findings have been made to allow for easier evaluation of data.

4 Oscillation Measurements

4.1 Log

File (folders)	Where	Descr.
Osc.pro	\\VAGROD\IDL\OSC	IDL source code used for all
AVI	\\VAGROD\IDL	Package used to read in .MOV
Preview_b.xls	\\VAGROD \TT_new\analysis\osc	Excel file used to read in data
Osc.xls	\\VAGROD \TT_new\analysis\osc	Excel file used to anaslyze profiles
Telltale.xla	\\FLETTE \Desktop\Speciale\Analysis	Excel file with routines for solving

		diff. equation

4.2 Data reduction

The films were analyzed with IDL routine osc, that runs a number of tasks/subroutines described below.

The first task is to determine when a single drop starts and ends and determine the frame numbers where a drop starts and ends. Here one enters the frame number to take a look at, and enters a negative number to accept. Fig. 11 shows an example when a oscillation is about to be set into motion.
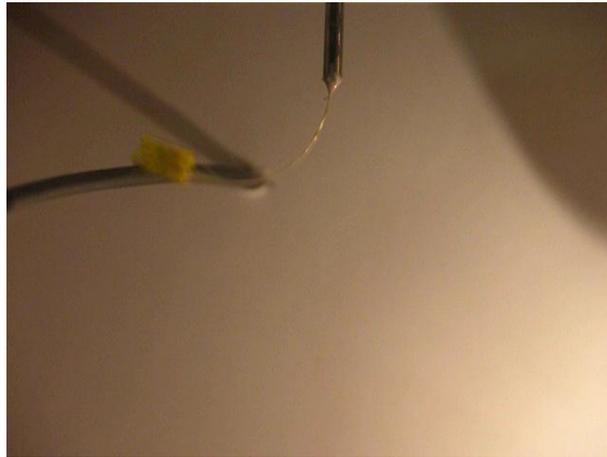
Fig. 11: First frame of an oscillation measurement.

The program then takes the average of the first 30 frames to work with. This averages out some of the JPEG compression features, and gives a picture of the position of the Kapton part during the first second. The value of 30 frames has been determined empirically, as using too few does not give a good picture of the position of the Kapton part, and too many overemphasize the low angle oscillations. Fig. 12 shows an example of the obtained average.
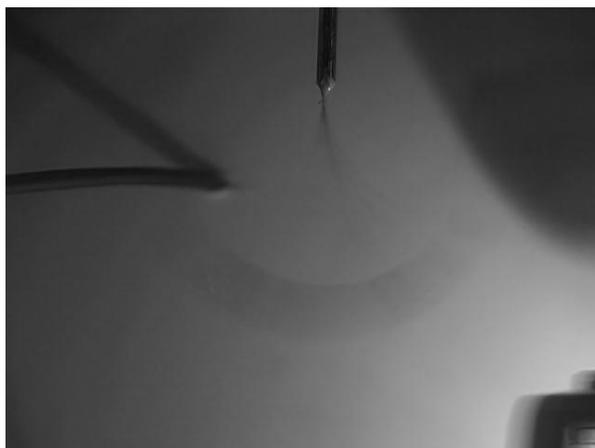
Fig. 12: Image obtained after averaging the first 30 frames of the oscillation film in the blue color,

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Due to low contrast, and varying background illumination, it is difficult to determine exactly where the active unit is. The user is prompted for ten points outside the Kapton part, a background model (plane intensity) is fitted to the image intensity of these points and a new picture generated that is scaled to enhance the position of the Kapton part. Fig. 13 shows an example of the generated image

Fig. 13: The same as Fig. 12, but the background illumination has been scaled to make the Kapton part of the Telltale better visible.

The user is then prompted for the points on the circles that define the upper edge of the Kaption foil and the lower edge. These are fitted two circles with the same origin, and used to determine that origin point where from the angle is determined, and the two radii in pixel coordinates. This data can in principle be compared to Tilt data, but is probably of less quality. It is not important how accurately this is done, as it will not affect the rate of damping nor the timing of the damping. Fig. 14 shows an illustration of what is determined.
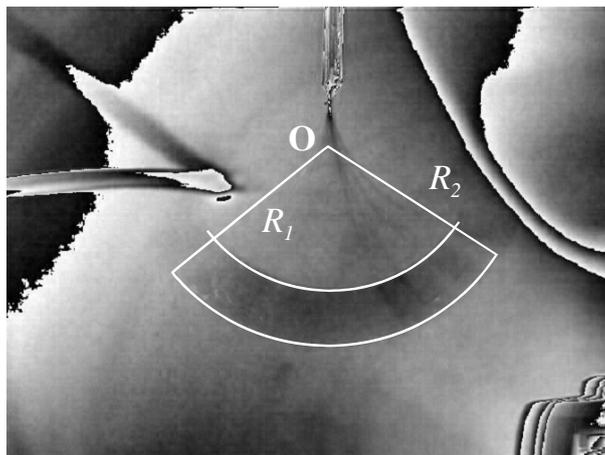
Fig. 14: Same as Fig. 13, indicating areas that are enhanced for the image analysis.

Profiles of the average image intensity are then obtained along the angle determined by the origin found above. This is done by finding an average of pixels that lie within the area defined by $\theta - \Delta\theta/2 < \theta < \theta + \Delta\theta/2$ and $R_2 < R < R_1$. $\Delta\theta$ was chosen such that a profile extending from $\theta = -\pi/2$ to $\pi/2$ would

consist of 200 points. The data obtained for all frames is written to a text file that is subsequently written into an Excel file for further analysis. Fig. 15 shows, as an example, the five first profiles obtained from the analysis of a film.
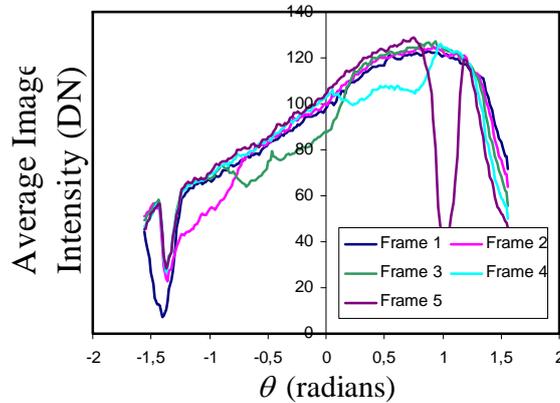
Fig. 15: Profiles of the Kapton part obtained in the first five frames. A lowering of intensity is observed moving from the left to right.

The profiles obtained are masked by the gradient in the background illumination, but still it is possible to follow the movement of the active unit along this background. To enable further analysis, all the profiles are normalized to maximum intensity.
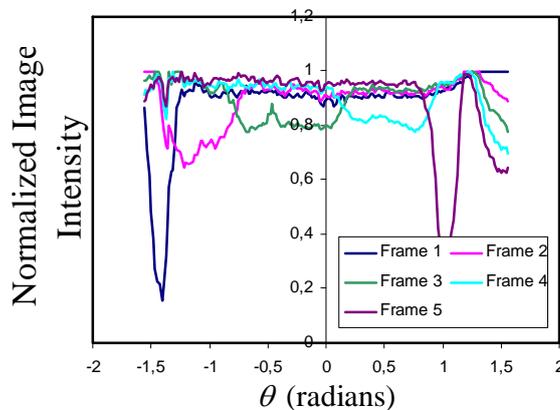
Fig. 16: Same as Fig. 15 but the profiles have been normalized to the maximum intensity in all frames.

All profiles have to be studied in detail, in order to see how to perform the automatic analysis of them. From the data displayed above, it is clear that the data at $\theta > 1.2$ rad. cannot be used, and one has to require normalized intensity < 0.9 to get meaningful analysis. In some cases, individual profiles may have to be altered. This gives the oscillation profile, as illustrated in Fig. 17 and the standard deviation in the angle as illustrated in Fig. 18.

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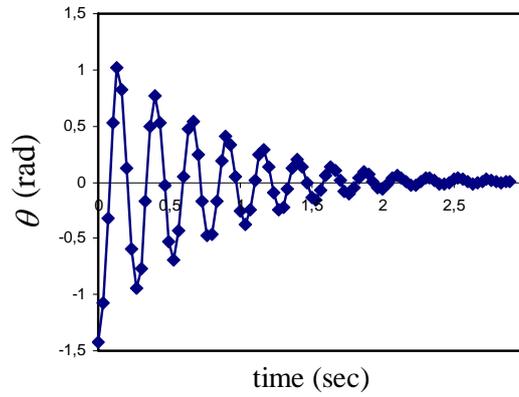
Fig. 17: Example of a drop profile.
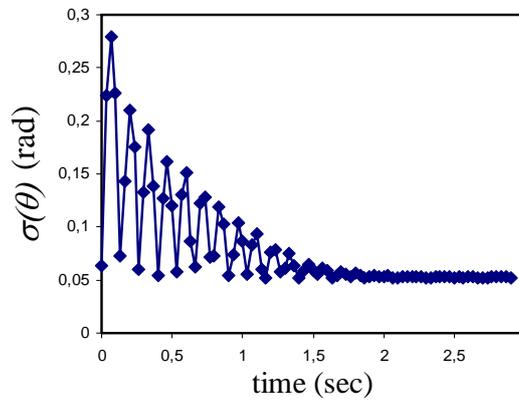
Fig. 18: Example of a standard deviation of the angular determination.

The standard deviation can be reduced to velocity of the Kapton part and applied into the analysis, but this has not been done at this stage.

4.3 Analysis

The drop data is analyzed in terms of Lagrangian with a Raleigh's dissipation function

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial L}{\partial \dot{\theta}}\right) - \frac{\partial L}{\partial \theta} + \frac{\partial F}{\partial \dot{\theta}} = 0$$

Where $L = T - U$ and F is Raleigh's dissipation function. Here we have for the kinetic energy

$$T = \frac{\rho^{(2)}}{2}\dot{\theta}^2$$

The potential energy comes from two sources, the gravity, U_G, at $\theta = 0$ and the Kevlar fibres U_K

$$U_G = \rho^{(1)} g (1 - \cos \theta)$$
$$U_K = A_K^{(1)} \theta^2 + A_K^{(3)} \theta^4$$

And Raleigh's dissipation function is written

$$F = \frac{1}{2} c \dot{\theta}^2$$

where c is the damping constant. The equation of motion yields:

$$0 = D \ddot{\theta} + \sin \theta + a_1 \theta + a_3 \theta^3 + C \dot{\theta}$$

Where

$$D = \frac{\rho^{(2)}}{\rho^{(1)} g}$$

$$C = \frac{c}{\rho^{(1)} g}$$

and the parameters a_1 and a_3 are defined as in the Tilt section.

4.4 Results

The model described above, was programmed and the final version was Damp_5 in the Telltale xla file. The last optimization can be found in osc.xls under \\GIBTAM\hpg\TT_new\analysis\osc".

In the geometry tested, the value of D is calculated to $2.25 \cdot 10^{-3}$ s^2, and there was not found any reason to not use this value. The value of C showed the following pressure dependence indicated in Fig. 19.
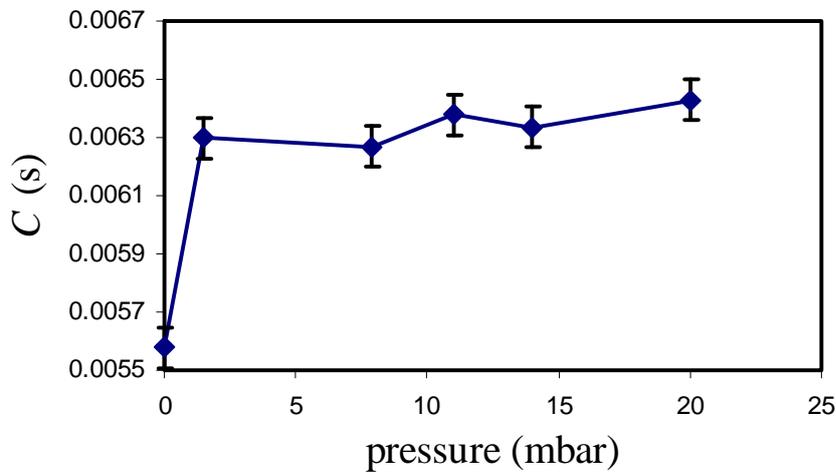
Fig. 19: Pressure dependence of the damping parameter C.

The pressure dependence is similar to data obtained of test units (see CDR files for comparison). This shows that the damping of the atmosphere is only of the order of $7 \cdot 10^{-4}$ s.

4.5 Frequency response

Having access to the dynamical model described above, it is possible to add a small AC (alternate current) term, and look at the frequency response. This is shown for terrestrial vacuum and Martian air in Fig. 20. This has not been calculated for all tilt angles, but the natural frequency increases of the order of ~10-20% at high tilt angles.
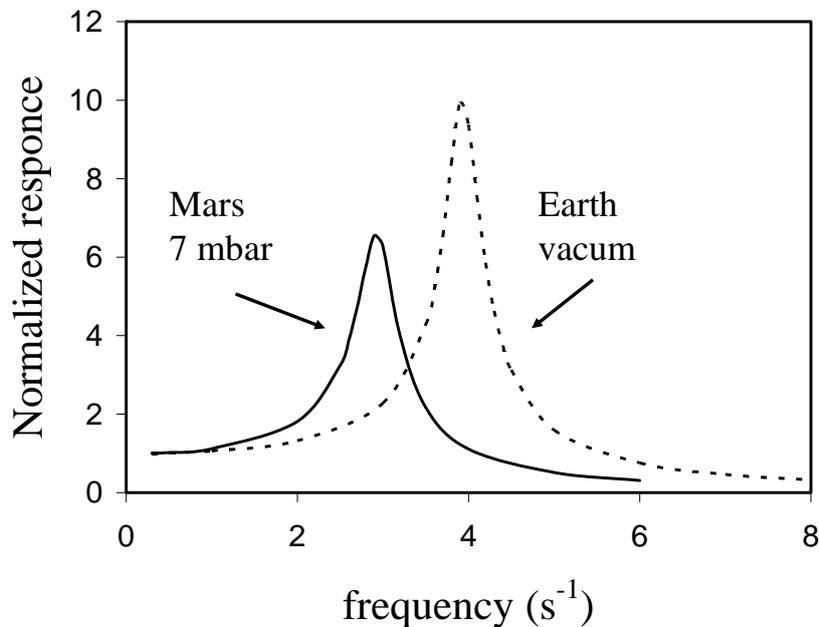
Fig. 20: Frequency response of the Telltale under the conditions indicated.

From this data, it will be possible to estimate that any smearing (or Δv) is ~7 times amplified at 3 Hz.

5 Wind Tunnel Measurements

5.1 Log

File (folders)	Where	Descr.
b14_routine.pro, screw.pro, Fit_Image.pro	C:\IDL\AVI on \\FLETTE	IDL source code for analysis
Telltale_addin.xla	C:\Desktop\Speciale\Anlysis on \\FLETTE	Add-in package for Excel with wind speed calibration data
Theta_b14#1_p8.xls, Theta_b14#1_p11.xls, Theta_b14#1_p14.xls, Theta_b14#1_p20.xls	C:\Desktop\Speciale\Analysis\WTC\p<*p*> on \\FLETTE	Excel files with data analysis
C:\hpg\TT_new\analysis\WTC	\\VAGROD	Diverse files

5.2 Introduction

The most important data from the calibration of the Telltale is the wind tunnel data. Here the deflection of the Telltale was measured as a function of wind speed under several different conditions. The greatest danger in these measurements was the risk of contamination, as the wind tunnel is by definition a dusty environment. However, by careful cleaning and limitations in wind speeds and pressures, it is possible to maintain a dust free environment. During the measurements, the dust content in the wind tunnel was measured using a Laser Doppler Anemometer (LDA). Not a single particle was counted (actually 16 particles are needed to make a LDA measurement) The wind speed is controlled by the frequency applied to the motor driving the fan in the wind tunnel.

The wind tunnel is calibrated (i.e. relationship between motor frequency and wind speed) using and dust in suspension. For these reasons, the wind tunnel was calibrated after the Telltale calibrations were finished.

5.3 Data

The wind tunnel data consists of a number of datasets of 35 sec films showing the Telltale in the wind tunnel at all combinations of 4 different pressures, P, and 8 different orientations, φ. For every combination 14 pre-chosen wind tunnel frequencies, f, were filmed for 35 sec giving a total of 32 datasets with 14 movies each. There are 30 frames per second giving us 1050 frames per film.

Due to loss of camera settings when changing the camera battery, about half of the datsets are focused, and the other half are unfocused. An example can be seen in Fig. 21.
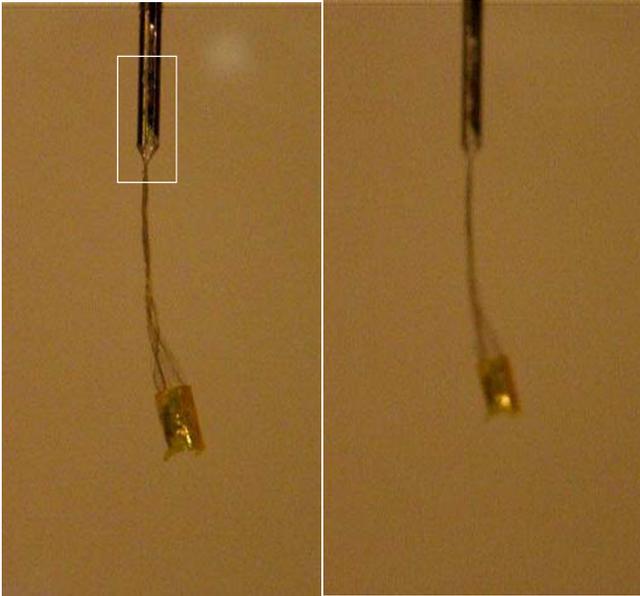
Fig. 21: LEFT: focused picture from the wind tunnel. The white box shows the cut used for finding the origo. RIGHT: unfocused picture from the wind tunnel.

The movies are stored in QuickTime™ format (end with *.MOV) and are stored under …\WTC\b14#1\p$<p>$\o$<\varphi>$ on various hard drives containing the raw data from the Telltale calibrations.

5.4 Wind tunnel calibration

At each setting used in the measurements of the Telltale, dust was injected into the wind tunnel. During the 8 mbar calibration, however, a bearing broke, which meant that the wind tunnel calibration took much longer than anticipated, as a different types of bearings were applied. The calibration has been given in the Telltale_addin.xla with the function:

```
Function Hz2vV2(ByVal p As Double, ByVal f As Long) As Double
```

Which gives the wind speed in m/s when applied the pressure p in mbar (integer) and f in Hertz (integer). Fig. 22 shows the calibration profiles.
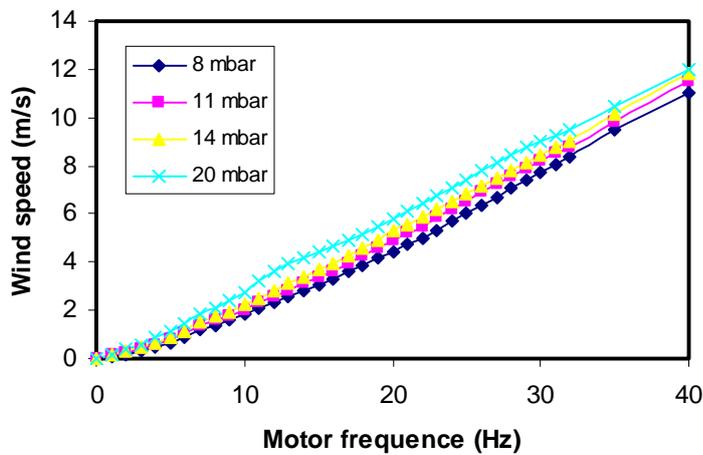
Fig. 22: Wind tunnel calibration profiles.

The 20 mbar curve appears to have a kink, but this is probably correct as the derived tilt curves become smooth with this calibration.

5.5 Data reduction

The Telltale datasets were analyzed with IDL routines in b14_routine.pro, screw.pro and Fit_Image.pro which do two things.

The first program uses the box described in Sec. 3.4 to find the position of the Telltale in all 1050 frames of a film.

The other programs find the angle of the screw, θ', and the position of the origo for the (x', y') coordinate system (the tip of the screw). This is done by fitting the small image in the white box shown in Fig. 21 to a calculated average picture of 100 frames from a movie. When fitting, the program ignores the Kevlar string because of its fluctuating position (see Fig. 23) and all fitting is done using the blue pictures. The fitting itself is accomplished by choosing an initial position for the origo, which the program then adjusts along with the magnification, blurriness, rotation and several intensity parameters for the smaller picture. The program returns the fitted parameters mentioned above, whereof we use the position of origo and rotation for further analysis. An example of a fit can be seen in Fig. 23.
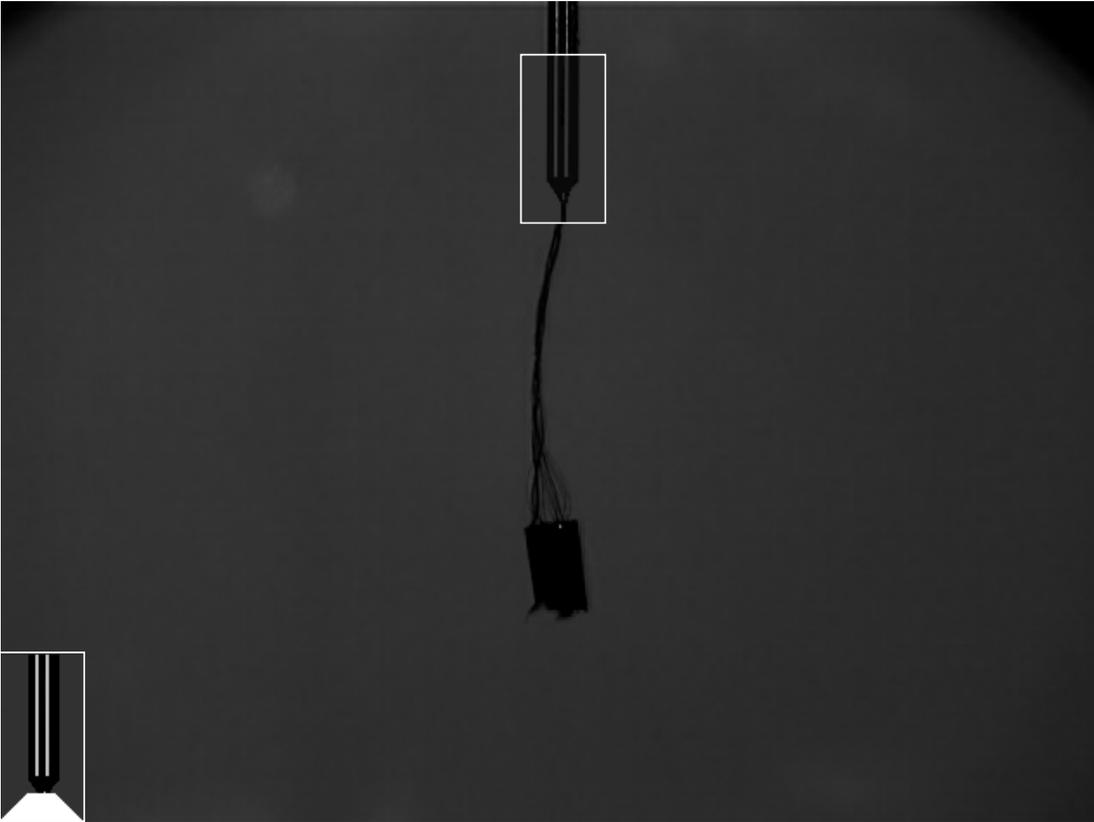
Fig. 23: BOTTOM LEFT: The white area is not used in the fit. BIG PICTURE: A fitted average picture, with the white box overlain to show the little picture that is fitted to the big picture.

For each folder the programs are run and all data is saved in *.txt files under …\WTC\b14#1\p<*p*>\o<φ>. This data is subsequently written to an Excel file for further analysis.

In version 1 of the calibration report, it has not been possible to reduce all movies. This is due to the fact that in many films, there have been difficulties in determining the screw position accurately due to reflections etc. Table 5 lists the available data. As the quality of the model obtained with this partial data has proven to be excellent, it is unlikely that the remaining data will ever be analysed.

Table 5: Datasets available in version 1 of the calibration report marked with an "X".

		Pressure (mbar)			
		8	11	14	20
Orientation, φ (°)	0	X	X	X	
	45				
	90	X	X		
	135		X	X	X
	180		X	X	X
	225		X	X	
	270	X	X	X	X
	315	X	X	X	X

5.6 Analysis

The first step concerns θ'. The rotation angle, r, is given by the program and expresses the angle through which the small image was rotated in the clockwise direction in order to make the fit. By definition θ' is thus equal to $-r$.

The second step involves finding the Telltale angle, θ, which is complicated by the matter that we are using definitions both from the wind tunnel and tilt analysis. These two systems do not use the same scale, and thus a scaling constant, α, is introduced in the calculations.
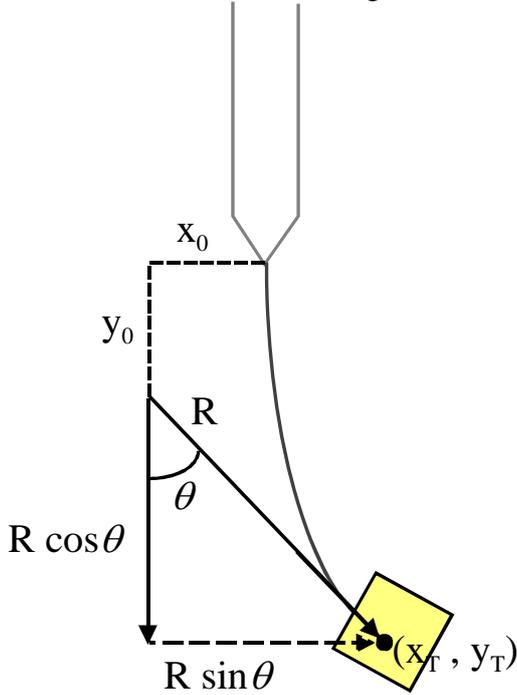
Fig. 24: Definitions used in determining θ

$$x_T = \alpha x_0 + \alpha R \sin \theta$$

$$y_T = \alpha y_0 - \alpha R \cos \theta$$

The position of the Telltale, (x_T, y_T) come from the data reduction of the wind tunnel data and is transformed from the (x, y) to the (x', y') coordinate system. x_0, y_0 and R come from the Tilt analysis and are scaled in relation to the wind tunnel data. Dividing the equations with each other and rearranging gives:

$$\cos \theta + \left(\frac{y_T}{x_T} \right) \sin \theta = \frac{y_0}{R} - \left(\frac{x_0}{R} \right) \left(\frac{y_T}{x_T} \right)$$

or in vector form:

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$$\left[1, \frac{y_T}{x_T}\right] \cdot \left[\cos\theta, \sin\theta\right] = \frac{y_0}{R} - \left(\frac{x_0}{R}\right)\left(\frac{y_T}{x_T}\right)$$

The left side is the cross product between two vectors which, through the cosine formula, is related to the angle between them, and is called ϕ. In a common coordinate system, each of the vectors have an angle with the first axis, which are, respectively, ξ, and θ. ξ is defined as:

$$\xi = \tan^{-1}\left(\frac{y_T}{x_T}\right)$$

Geometry shows that the Telltale angle, θ, can be calculated as:

$$\theta = \xi - \phi \text{ for } \xi > 0$$

and

$$\theta = \xi + \phi \text{ for } \xi < 0$$

Fig. 25 shows a series of average deflection angles at different air pressures.
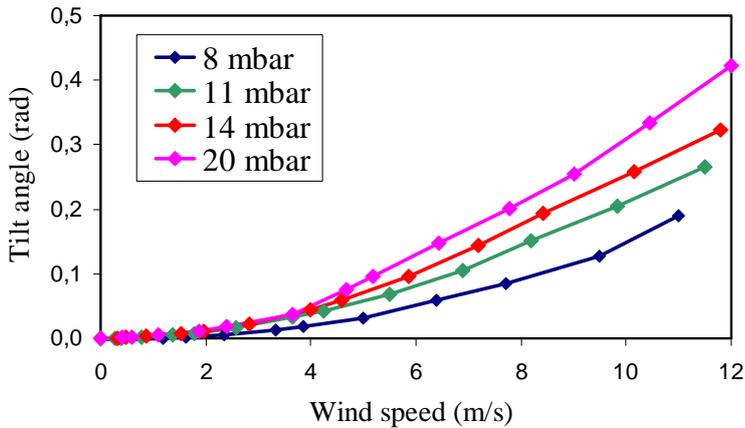
Fig. 25: Average deflection of the Telltale (averaged over available orientations) for different pressures.

The Excel files used for data analysis were named Theta_b14#1_p<*p*>.xls and are located in …\Analysis\WTC\b14#1\o<φ>.

5.7 Model of the Telltale

We set up a model of the energy of the Telltale as:

$$U = U_G + U_K + U_W$$

Where U_G is the gravitational part, U_K the Kevlar part and U_W the wind contribution. As found previously we write:

$$U_G = \rho^{(1)}(\varphi)g(1 - \cos(\theta' + \theta))$$
$$U_K = A_K^{(1)}\theta^2 + A_K^{(3)}\theta^4$$

The wind contribution U_W should be divided into drag part U_D and a lift part U_L. The drag potential energy onto a cylinder of width D and length L, that tilts in the wind can be written

$$U_D = \frac{C_D(\text{Re})L^2 D \rho v^2}{4}\left|\frac{\theta}{2} + \frac{\sin(2\theta)}{4} - \frac{\pi}{4}\right|$$

Where $C_D(\text{Re})$ is the drag coefficient, depending on the Reynolds number

$$\text{Re} = \frac{D\rho v}{\mu}$$

The useful range of wind velocities for the Telltale is 1-10 m/s, meaning Reynolds numbers up to ~62. The lift part can be written in a similar way with the identical pre-factor but a different angular dependence. Since the Telltale is far from being an ideal cylinder, lift has to be taken into consideration. We use a generalized function for the wind contribution since the lift part is not expressed as easily as the drag part.

$$U_W = C_1 \cdot C_D\left(C_2 \frac{\rho v}{\mu}\right) \cdot \rho v^2 \cdot f(\theta)$$

Where C_1 and C_2 are fitting variables. In SI units, C_1 should be larger than 5×10^{-8} m^3, and C_2 around 4×10^{-3} m. To find the minimum, one needs to differentiate with respect to the angle, and solve. An empirical way is used to find $f(\theta)$ instead of using theory. When solving for the angle θ, one applies

$$\frac{\mathrm{d}U}{\mathrm{d}\theta} = 0 \Rightarrow \frac{\mathrm{d}(U_G + U_K)}{\mathrm{d}\theta} = -C_1 \cdot C_D\left(C_2 \frac{\rho v}{\mu}\right) \cdot \rho v^2 \cdot \frac{\mathrm{d}f(\theta)}{\mathrm{d}\theta}$$

Since U_G and U_K are known, we can obtain the quantity $\dfrac{\mathrm{d}f(\theta)}{\mathrm{d}\theta}$. It turns out, that it followed closely an expression given by

$$\frac{\mathrm{d}f(\theta)}{\mathrm{d}\theta} = -B + A \cdot e^{-k\theta}$$

Where *A*, *B* and *k* are some parameters. This quantity can not be determined apart from a scaling factor (included in C_1), so we optimized all profiles assuming

$$\frac{\mathrm{d}f(\theta)}{\mathrm{d}\theta} = -1 + a \cdot e^{-k\theta}$$

Having analysed all profiles under different orientations, it turned out that the deflection did not show as prominent variation in orientation as suggested by the Kevlar stiffness constant. This lead to a re-examination of that data. The final set of parameters obtained is given in Table 6.

Table 6: Calibration constants for the F014 telltale

Parameter	Value
C_1 (m^3)	$3.46(6) \cdot 10^{-7}$
C_2 (m)	$4.12(24) \cdot 10^{-3}$
a	0.628(38)
k	18.3(13)

A series of Excel functions make use of these constants, to predict the position of the Telltale. A comparison between model and data from the wind tunnel is shown in Fig. 25
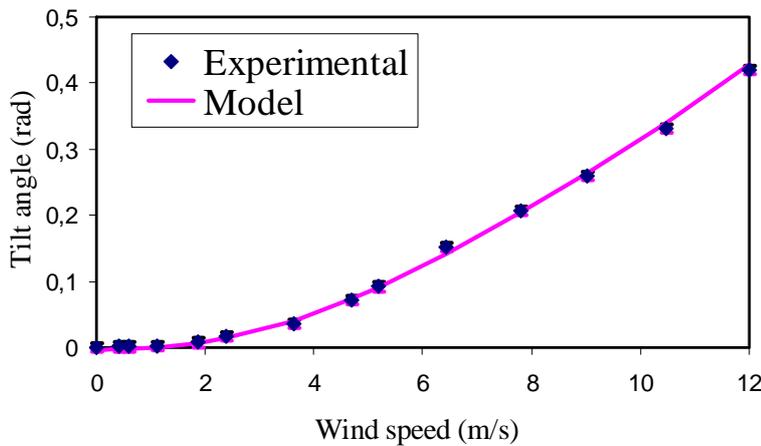
Fig. 26: Example analysis of a deflection angle profile. The data is taken at 20 mbar under $\varphi = 315^{\circ}$.

5.8 Excel functions

A great number of Excel functions have been fabricated for these purposes. A list of the important functions is given below

Table 7: Functions defined in the Telltale_addin.xla. The most important function is the `UtSolve3` function used to predict the position of the Telltale.

Parameter	Excel function	Comments
$U_G(\theta)$	Function UG(ByVal theta As Double, ByVal mgl As Double) As Double	theta given in radians, and mgl = $\rho^{(1)}$g where can be calculated with

		the Excel function MI(1,R), where R is in mm.
$U_K(\theta)$	Function UKevlar(ByVal theta As Double, ak1 As Double, ak2 As Double) As Double	theta given in radians.
$\theta \Leftrightarrow \dfrac{dUt}{d\theta} = 0$	Function UtSolve3(ByVal mgl As Double, ByVal ak1 As Double, ByVal ak2 As Double, ByVal C1 As Double, C2 As Double, aa As Double, kk As Double, v As Double, rho As Double, my As Double) As Double	Parameters as defined above. The function delivers θ in radians.

All the energy functions exist also in differentiated form with the same parameterization but the name of the function is then with an added "d" e.g. UKevlar -> UKevlard.

5.9 Modeling of parameters for wind tunnel

The parameters used in the wind tunnel are the wind velocity v measured in m/s, Pressure P measured in mbar, and orientation of the Telltale, φ. The orientation should give the value of the parameters A_K's and R.

5.9.1 Density, ρ

The pressure gives indirectly the density ρ of the medium. The Excel function AirDens(P [mbar]; T [$^{\circ}$C]) calculates the density in kg/m^3 for dry air. Using the assumption that the atmosphere on Mars is an ideal CO_2 gas, the density on Mars can be calculated using the formula:

$$\rho_{\text{MARS}} = 0.5366\, P\,[\text{mbar}]/T\,[\text{K}].$$

5.9.2 Viscosity, *µ*

We apply Sunderland's formula (Crane, 1988) for the viscosity;

$$\mu = \mu_0 \times \frac{0.555 \cdot T_0 + C}{0.555 \cdot T + C} \times \left(\frac{T}{T_0}\right)^{(3/2)}$$

Where C and T_0 are, respectively, the Sunderland's constant and the reference temperature. The values are taken from "http://www.lmnoeng.com/Flow/GasViscosity.htm" that is based on the CRC catalogue. These are the same values applied by Nilton Renno in his description of sample delivery experiments for the Phoenix mission. The XLS function my_mars(T) calculates the viscosity in SI units when given the temperature in K.

6 Tilt Images

6.1 Data

Tilt images were obtained using three cameras with the geometry shown below
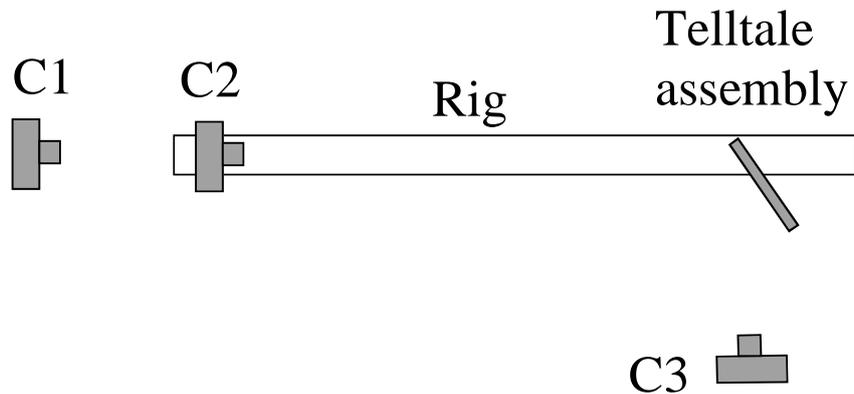
Fig. 27: Schematic image of the setup used for Tilt Images.

The Telltale assembly is mounted on a rig that can be rotated in all different positions, thereby giving all possible tilt angles of the active unit by making use of the gravity pull. The cameras labeled C1 and C2 take pictures of the assembly to document the orientation and position of the active part of the Telltale. The C3 camera takes images in a position that should resemble the right eye of the SSI.

The description of the images is given below:

Camera	Format
C1	JPG 1632x1224 taken with a JVC Everio G Series hard disc camcorder. Images always labelled "PIC_<*seq. no.*>.jpg", size usually ~ 600 kB
C2	TIF 3264x2448 taken with a Nikon 8800. Images always labelled "DSCN<*seq. no.*>.tif", size 23520 kB
C3	JPG 3264x2448 taken with a Nikon 8700. Images always labelled "DSCN<*seq. no.*>.jpg", size ~ 2600 kB

The data is stored under "…\TiltImag\<*FM model*>\o<*label*>. Where <*FM model*> is either F012 or F014. o<*label*> labels the set with elevation rotation. For each elevation, the rig was rotated into 30-40 positions.

The first image in each set is taken with a string hanging in the picture field, to allow for corrections of gravity angles in case the cameras are misaligned. A typical set for this starting orientation is shown in Fig. 28.
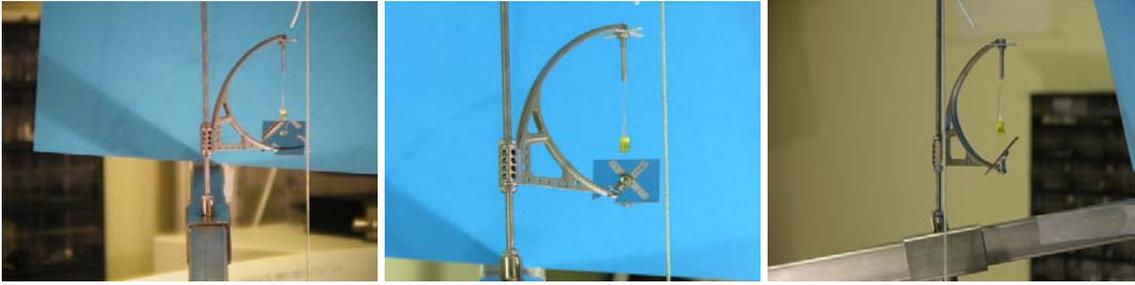
Fig. 28: Images of the Telltale taken with cameras C1 (left) C2 (middle) and C3 (right) with a string giving the direction of gravity.

Subsequent images are taken at different orientation angles. Some examples of tilts are shown in Fig. 29.

Fig. 29: Selected Tilt Images.

6.1.1 Catalog of image data

There is a wealth of information in the images which need to be reduced. First of all the images have to be catalogued, in order to know which images belong together. This has been done by using the creation time of each image, and the results are stored in a file labeled "*<FM model>* _o*<label>*.dat" in the analysis folder. Below is shown a typical data from the "F014_o0.dat" file.

```
G:\TiltImag\F014\o0
 0           PIC_0334.JPG  DSCN0694.TIF  DSCN0683.JPG
 1           PIC_0335.JPG  DSCN0695.TIF  DSCN0684.JPG
 2           PIC_0336.JPG  DSCN0696.TIF  DSCN0685.JPG
 .
 .
 .
```

The first line gives the file number, where 0 is always the one with the string.

6.2 First analysis of Tilt-Images

6.2.1 Introduction

A analysis was conducted with the first version of the code prepared for the analysis of images from Mars. The analysis was restricted to those images simulating SSI images. The goal of this analysis was twofold:

(1) Build up a database that would allow us to take a better look at how the images should look under different conditions
(2) Find out better ways to analyze the images to build into the program

The Tiff images from C2 were rescaled to approximate resolution expected on Mars and the blue color used. This meant reducing the resolution by factor seven. The findings have been described in the document "TiltImages_part.doc", that at this stage includes mostly recommendations for the next version of the program.

7 Telltale Mirror calibration

7.1 Introduction

The purpose of this calibration is to obtain data on the mirror quality, sufficient for the mirror to be calibrated in terms of defects and color. The procedures used here were presented at the Telltale CDR and accepted.

7.2 Items calibrated

Three mirrors (UAP-PHX-621-b) were made as potential flight models (S/N: F001-F003). From the workshop they were given serial numbers in order of visual quality. The F003 has a small scratch that did not disappear during polishing.

7.3 Description of the calibration

A schematic drawing of the setup used is shown Fig. 30
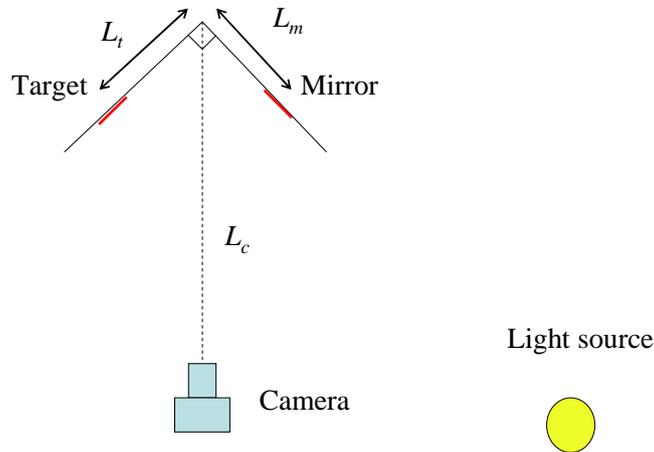
Fig. 30: Schematic picture of the setup used for mirror calibration. Both the target and the mirror are imaged in the same frame.

The camera is situated as far from the target and mirror as possible in the same level as the target and the mirror. The light source is a window in the end of the laboratory. The target is mounted in such a way that reflection from the mirror is avoided. Distortion images are taken using two orientation of the mirror. In all cases, the distance to the camera L_c was 135 cm and $L_m = L_t = 150$ mm.

7.3.1 Targets and images

The color target consists of color tiles cut from colored paper, giving a wide spectrum of reflections in each color. The alignment target consists of a sheet with lines separated at 1 mm each. Images are taken using Nicon Coolpix 8700, with resolution 3264x2448 with standard red, green and blue colors.

Fig. 31 shows an image of the color target together with definitions.
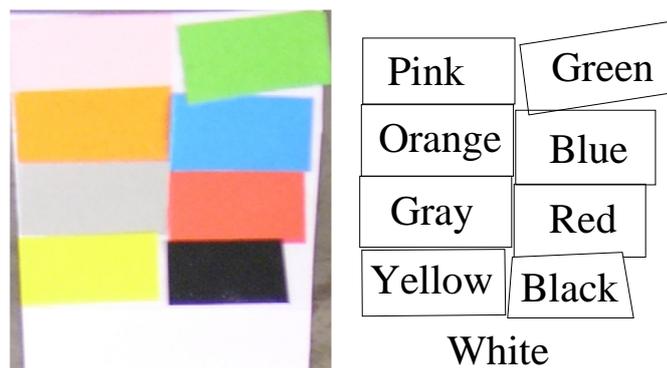
Fig. 31: Image of a color target used for mirror calibration. The naming convention used is shown to the right.

7.4 Analysis

7.4.1 Color target

For a representative image one finds the data number (DN) in each camera color and tile. Remaining pictures are checked for consistency.

7.4.2 Alignment target

Maximum distortion is found from a representative image and given in degrees from ideal reflection. The remaining images are checked for consistency and the data stored for future usage.

7.5 Data

Table 8 lists the images available under the "TT_new\MirrorCal" folder.

Table 8: Calibration data. The images are named DSCN<no>.jpg, where the number <no> is listed in the table.

UAP-PHX-621-b, S/N	Alignment target in orientation #1	Alignment target in orientation #2	Color target
F001	5171	5172, 5173	5174
F002	5175	5176, 5177	5178
F003	5179	5180	5181

7.6 Results

7.6.1 F001

7.6.1.1 Color
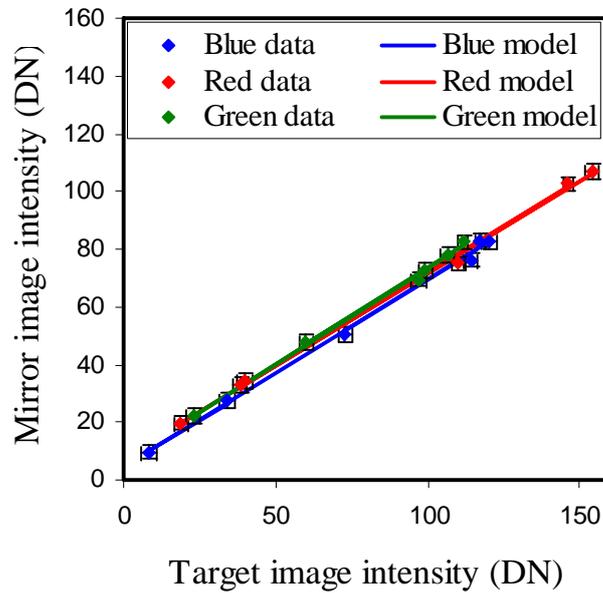
Fig. 32: Color calibration of F001 mirror.

It is assumed that an offset in the intensity is an artifact of the camera, and not taken into consideration. The table below shows the slope in each color

Table 9: Results of analysis of the color targets for the F001 mirror.

color	Slope
blue	0.65(3)
green	0.67(3)
red	0.64(2)

There is no apparent difference between colors. There has not been observed any significant difference in the color reflection of any mirror made, so if better findings are needed, one can always recalibrate one of the spare units.

7.6.1.2 Image distortion
The image distortion of the mirror has become smaller with the new procedures of making them. The maximum image distortion is roughly 5 mrad.
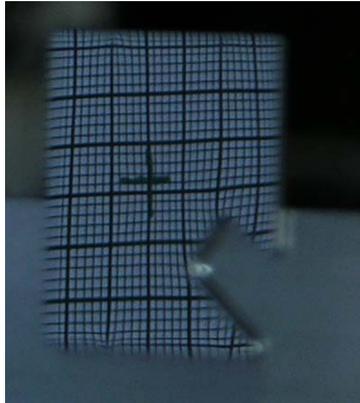
Rough pattern matching (by hand) shows reasonable results at centre, but as high as 1 mm discrepancy at the edges, and less than 0.5 mm in the well useful central area.

7.7 Conclusions

As the distortion in the mirror labeled F001 was found to be slightly better by visual inspection, this unit was selected for flight, while the mirrors labeled F002 and F003 are used for the spare unit. Based on the true dimension of the flight unit, the distance to the Kapton foil will be of the order of 15 mm, while the calibration is made at ~200 mm. 0.5 mm distortion in calibration images should result in 0.04 mm distortion in the mirror image., which is take as the maximum error.

8 ATLO imaging.

8.1 Data

There data was downloaded from "http://www.lpl.arizona.edu/~adams/Telltale_images.zip" given by email from Adam Shaw 28. march 2007. The zip package contains three folders:

1. 070201_FMSSI_ATLO: These are images of the old EQM model and are not of interest here.

2. Telltale_install: This seems to be the files obtained during installation of the Telltale.

3. 070216_FMSSI_SVT_Day3: These are few images taken in both left and right filter that seem interesting, but may not be the most important files.

In all cases two types of jpg versions exist plus a vicar format file and a header file.

8.2 Files in "Telltale_install"

The images can be classified according to the mission time embedded in the filename. First, there is a range of images taken in R7 (753 nm diopter), R1 (672 nm geology filter) and R6 (445 nm diopter). These seem to be taken while the rotation of the Telltale was adjusted. The pictures are shown below:
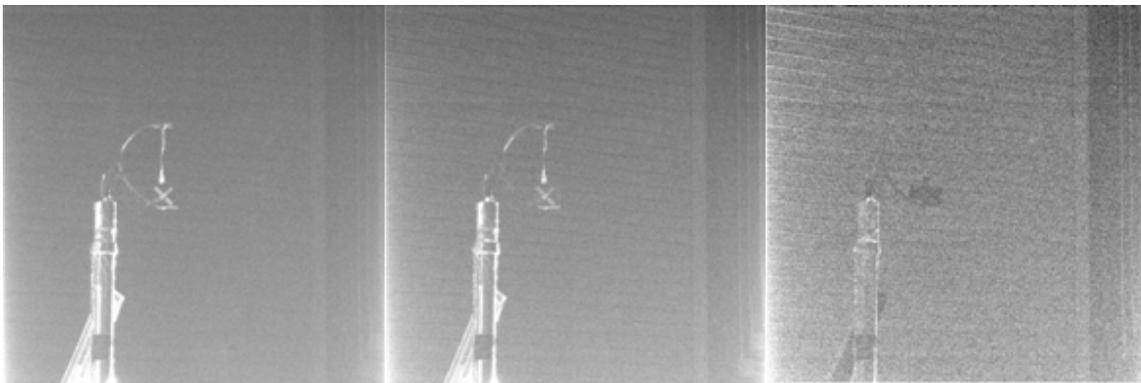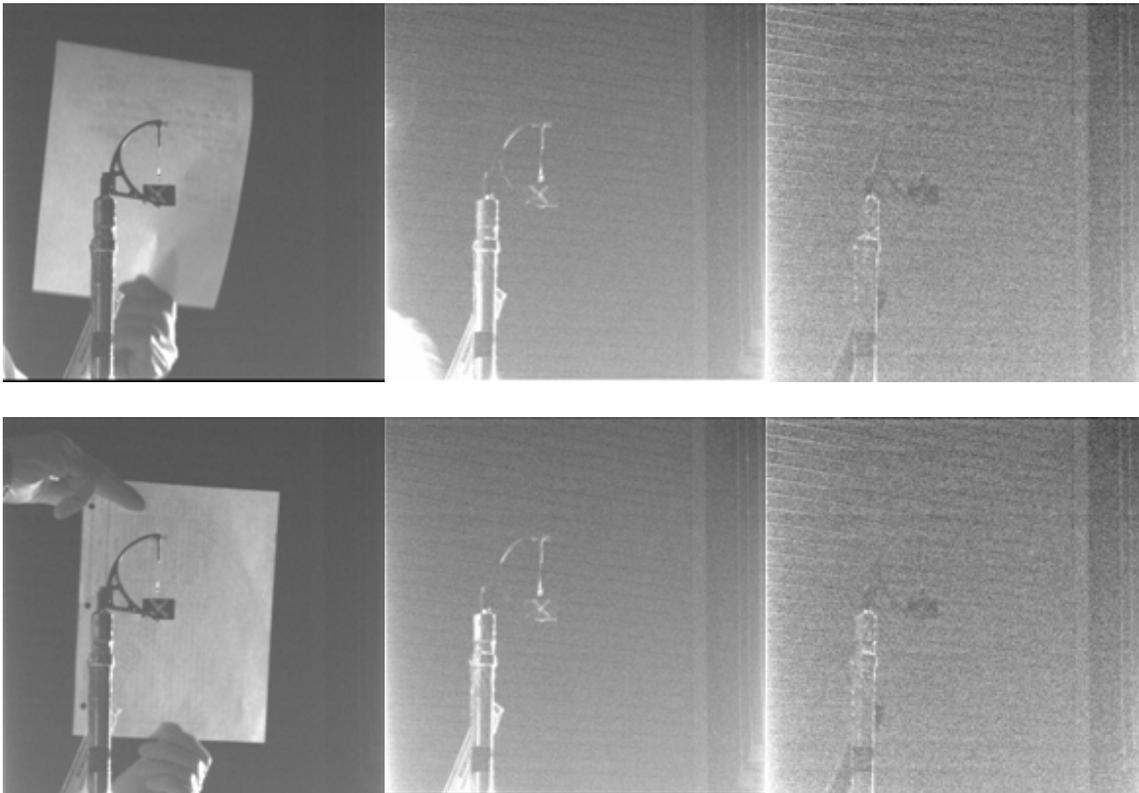
The final R7 picture obtained here seems to be the best one. Some data for this picture (ST033EDR854917075R7005000M1.VIC)

Place	Intensity (DN)
Paper (behind gallows)	700
Gallows	~450
Kapton	Up to 2500
Mirror (background)	475
Mirror (marker)	~550
Noise (paper)	~75

The Gallows is picking up as a D(DN) ~ 350 feature in a background with 75 DN noise (S/N 4.5). Would be nice to know what kind of a S/N we may expect. The last part of the images is taken during movement of the imager, in the jpg versions, they look worse, but this is an artifact due to overexposure. Some of these images are shown below.
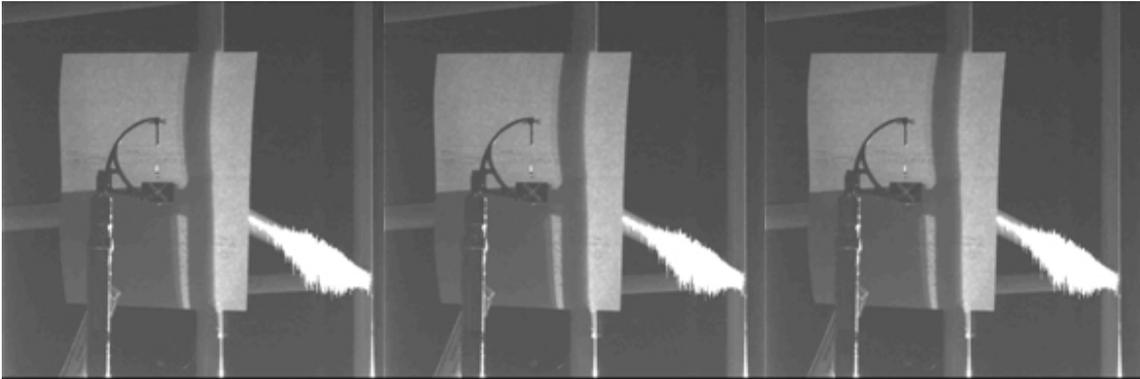
The best image to use to verify the position of the fibers is ST033EDR854915981R7005000M1 shown below, in comparison to an image from the calibration data.
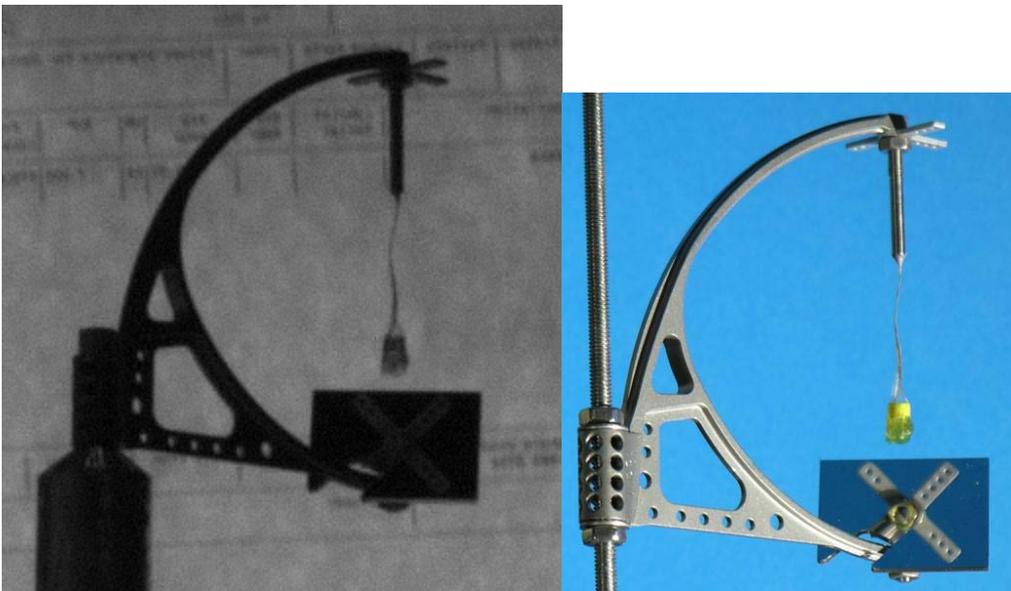
There is no detailed difference between the layout of the Keflar fibres meaning that the Telltale has not been exposed to bad treatment. Furthermore, the calibration data seems to be taken with the correct geometry.

9 Evaluation of PIT images of the Telltale from post ORT7

We received images from Mark Lemmon taken by Adam Shaw with different compressions. The hope is that this can be used to evaluate the effect of compression and result in better estimate of what we can allow us in compressions as we arrive at Mars. The header info gives strange info regarding the compression ratios, that I need explanation of. This set of images can without a doubt be used to test the effect of compression.

9.1 Table of images

I extracted some key data from the files, header lines 155 to 159.

Image	Mode	Quality	Rate	Ratio
SC344EFF896256093_00000R4M1.VIC	1	76	0.0523987	5.0
SC344EFF896256184_00000R4M1.VIC	1	76	0.0524597	5.0
SC344EFF896256274_00000R4M1.VIC	1	62	0.0739746	3.0
SC344EFF896256365_00000R4M1.VIC	0	A'	'N/A'	'N/A'
SC344EFF896256451_00000R4M1.VIC	1	96	0.0375061	9.0
SC344EFF896256546_00000R4M1.VIC	1	35	0.110657	12.0
SC344EFF896256632_00000R4M1.VIC	1	74	0.0548706	5.0
SC344EFF896256720_00000R4M1.VIC	1	76	0.0532532	5.0
SC344EFF896256813_00000R4M1.VIC	1	62	0.0745544	3.0
SC344EFF896256900_00000R4M1.VIC	0	A'	'N/A'	'N/A'
SC344EFF896256990_00000R4M1.VIC	1	96	0.037384	9.0
SC344EFF896257081_00000R4M1.VIC	1	46	0.0835266	12.0
SC344EFF896257171_00000R4M1.VIC	1	76	0.0529785	5.0
SC344EFF896257259_00000R4M1.VIC	1	76	0.0530396	5.0
SC344EFF896257352_00000R4M1.VIC	1	62	0.0744324	3.0
SC344EFF896257440_00000R4M1.VIC	0	A'	'N/A'	'N/A'
SC344EFF896257525_00000R4M1.VIC	1	96	0.0372009	9.0
SC344EFF896257620_00000R4M1.VIC	1	46	0.0837708	12.0
SC344EFF896257706_00000R4M1.VIC	1	76	0.0531616	5.0
SC344EFF896257797_00000R4M1.VIC	1	76	0.0535278	5.0
SC344EFF896257886_00000R4M1.VIC	1	62	0.0745544	3.0
SC344EFF896257977_00000R4M1.VIC	0	A'	'N/A'	'N/A'
SC344EFF896258062_00000R4M1.VIC	1	96	0.0377808	9.0
SC344EFF896258155_00000R4M1.VIC	1	46	0.0839539	12.0
SC344EFF896258242_00000R4M1.VIC	1	76	0.0532227	5.0
SC344EFF896258329_00000R4M1.VIC	1	76	0.0530396	5.0
SC344EFF896258422_00000R4M1.VIC	1	62	0.074646	3.0
SC344EFF896258509_00000R4M1.VIC	0	A'	'N/A'	'N/A'
SC344EFF896258599_00000R4M1.VIC	1	96	0.0372925	9.0
SC344EFF896258688_00000R4M1.VIC	1	46	0.0838318	12.0

There is no correlation between the RATE and RATIO, which means that I am a bit lost here. It is though clear that the images group by the RATIO number.
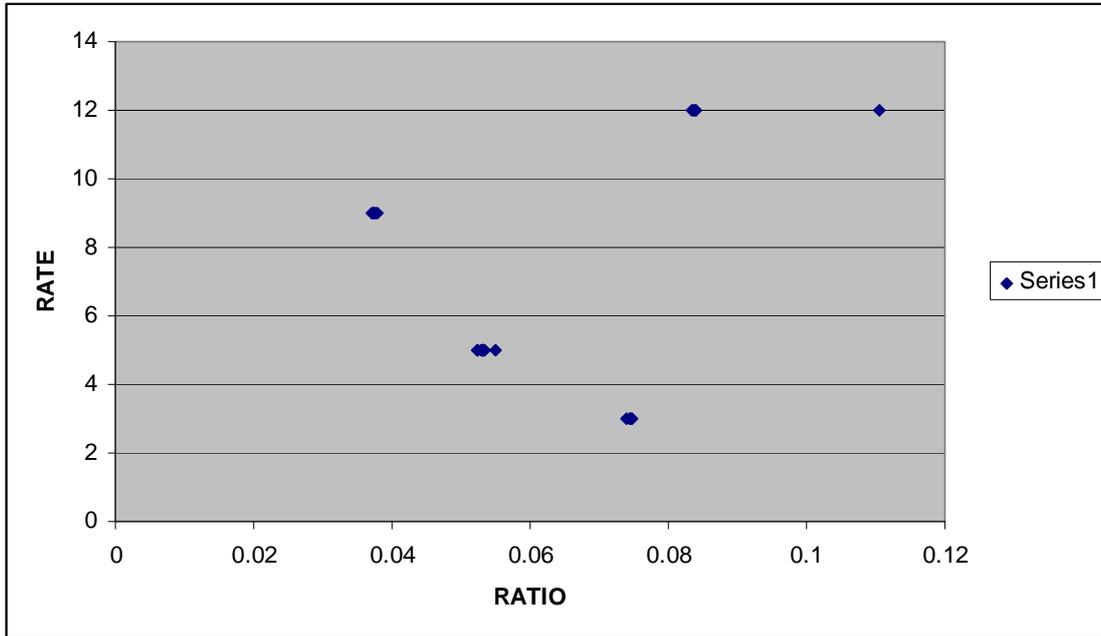
9.2 Visual inspection

9.2.1 Ratio='N/A' SC344EFF896256365_00000R4M1.jpg
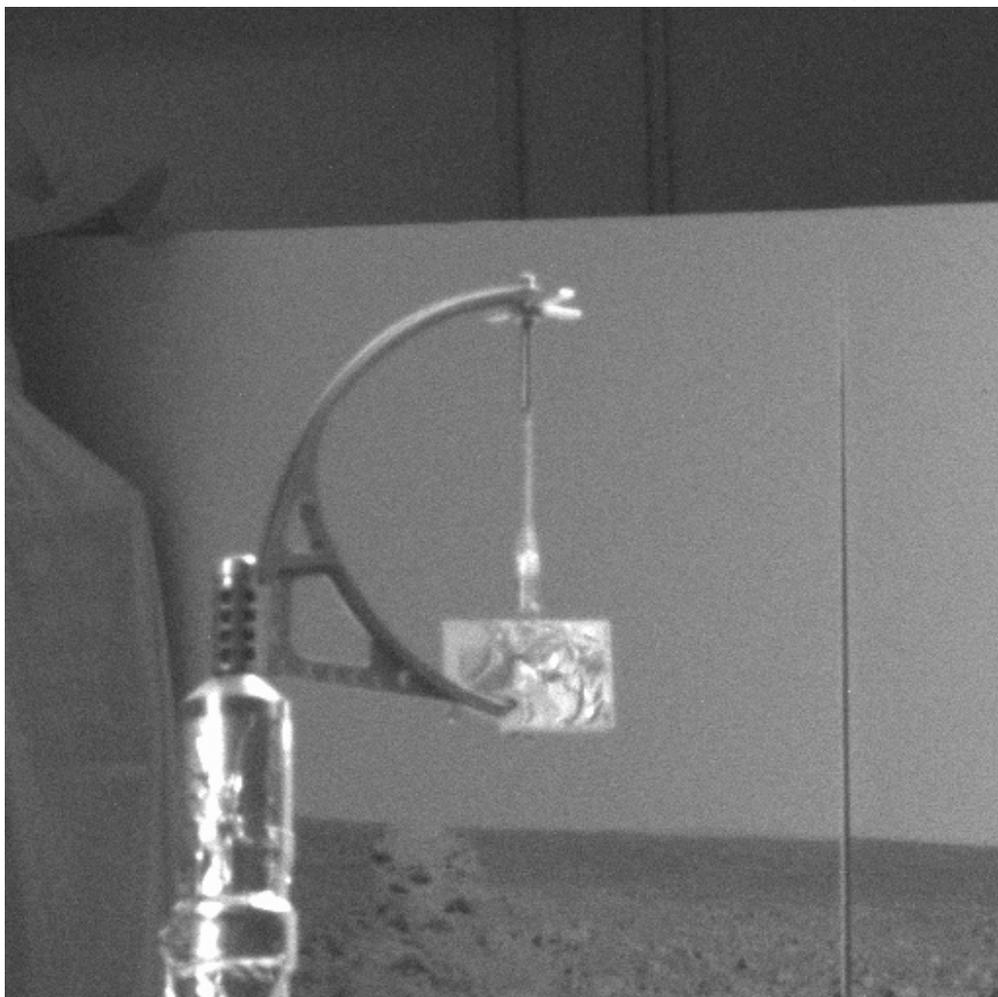
9.2.2 Ratio=12 SC344EFF896256546_00000R4M1.VIC
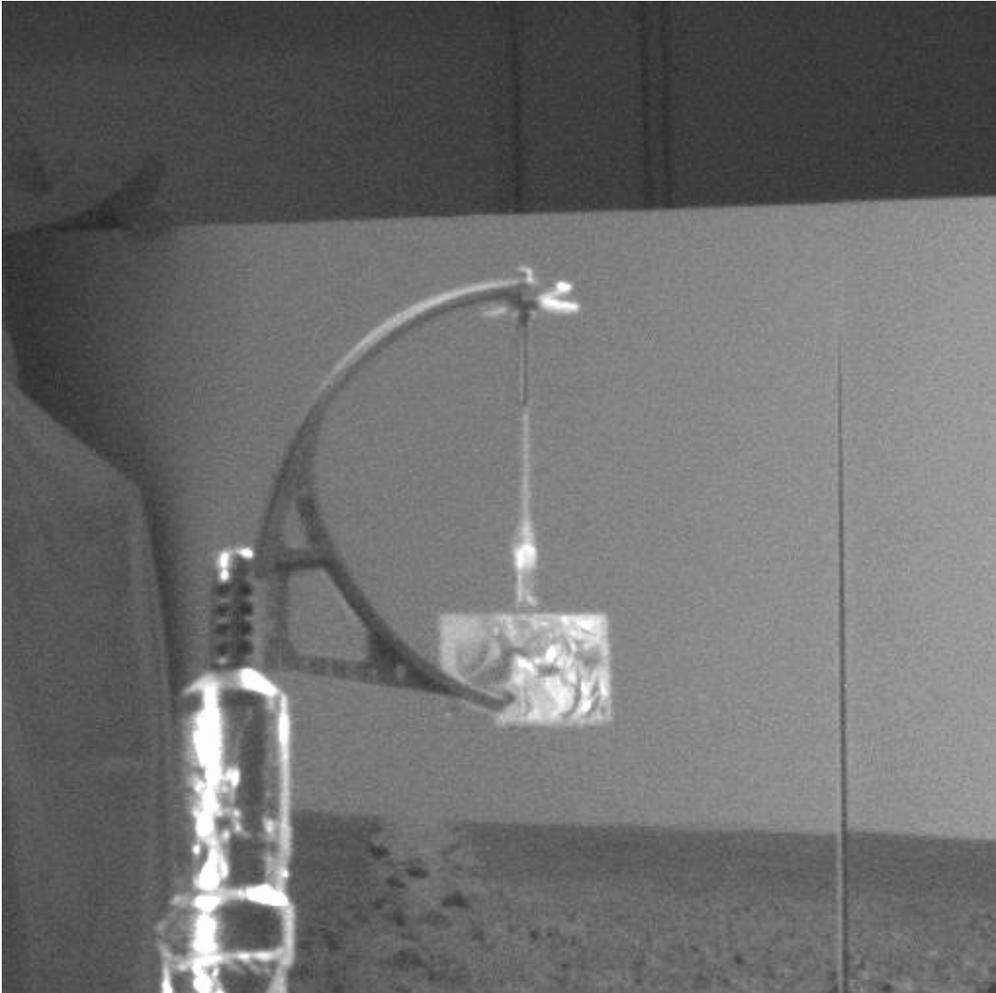
9.2.3 Ratio=3.0 SC344EFF896256274_00000R4M1.JPG
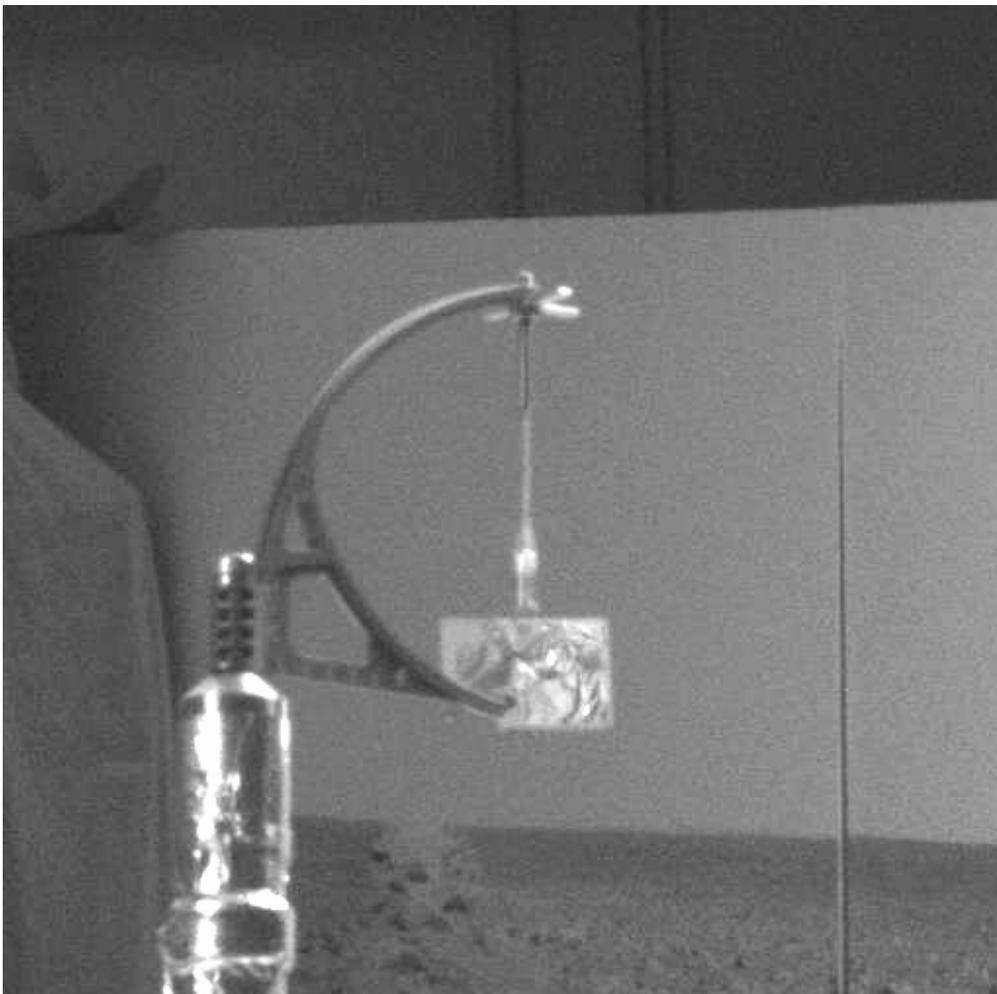
9.2.4 Ratio=5, SC344EFF896256093_00000R4M1.VIC
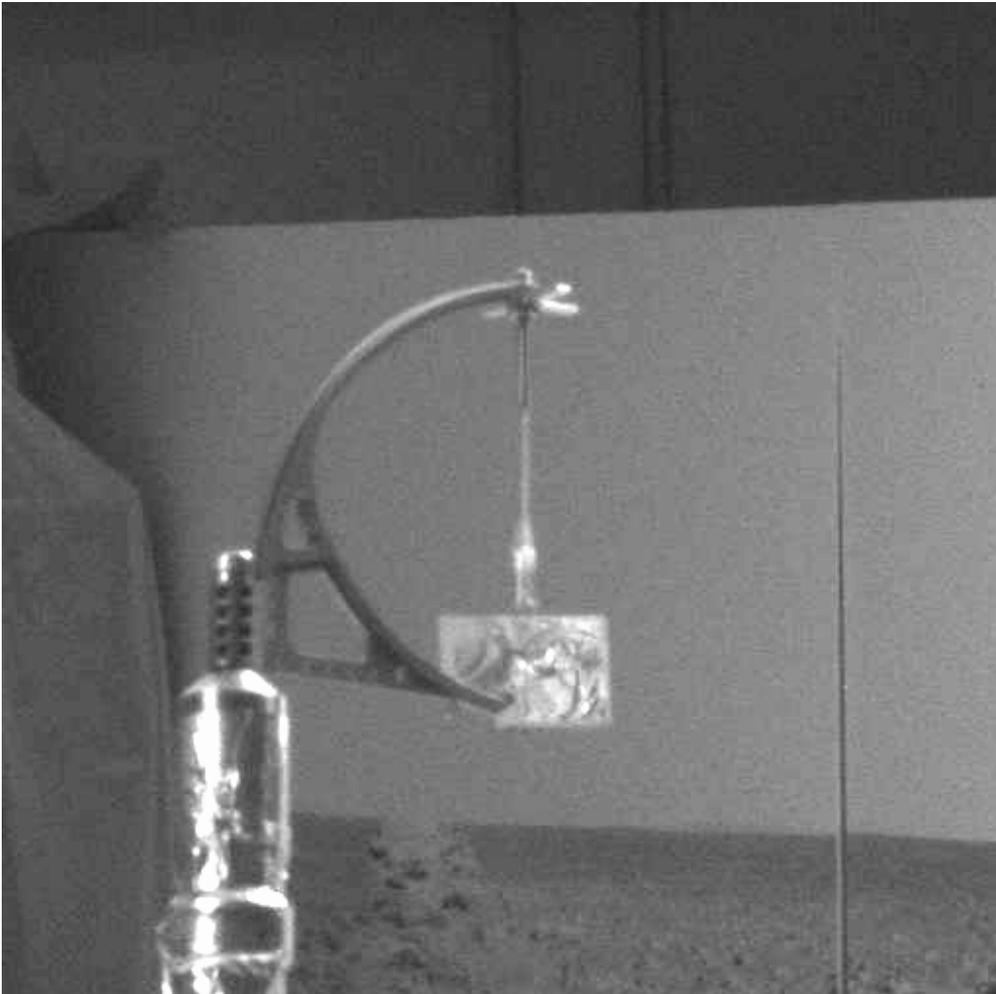
9.2.5 Ratio=9.0 SC344EFF896256451_00000R4M1.JPG
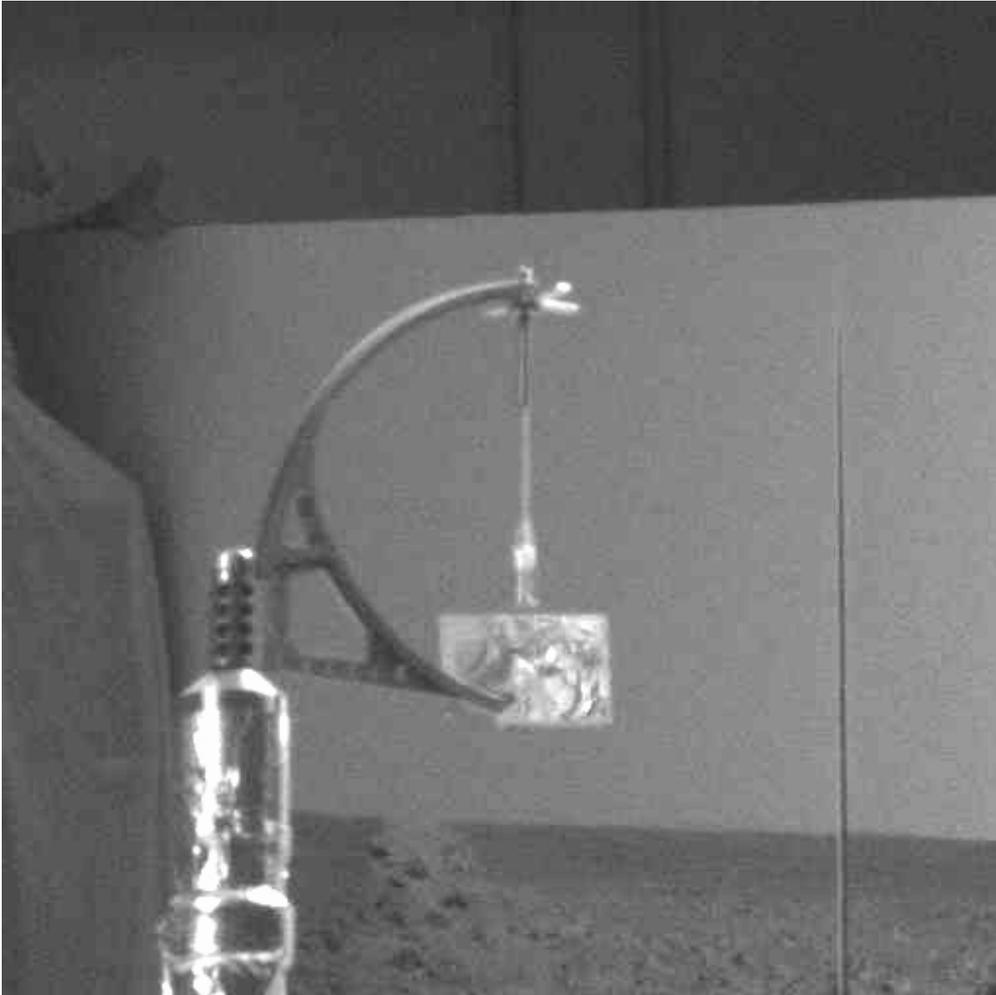
9.3 Conclusions from visual inspection

It is clear that the rate number is the relative compression scale, and this is best seen in the relatively homogeneous background, where typical jpeg compression artifacts come up. This corresponds to the size of the jpg files, but has no relation to the ratio number nor quality number. Based on the visibility of some minor details in the figures, it appears that we can work with considerably high compression, but this will have to be tested.

10 Interpretation of data from Mars

10.1 Using the model of the Telltale

Using the model set up in Section 5.7, we can make an assessment of the amount of the deflection of the Telltale we will expect to see on Mars. As we see a wind speed on Mars of 10 m/s will give us a deflection of close to 1 cm.
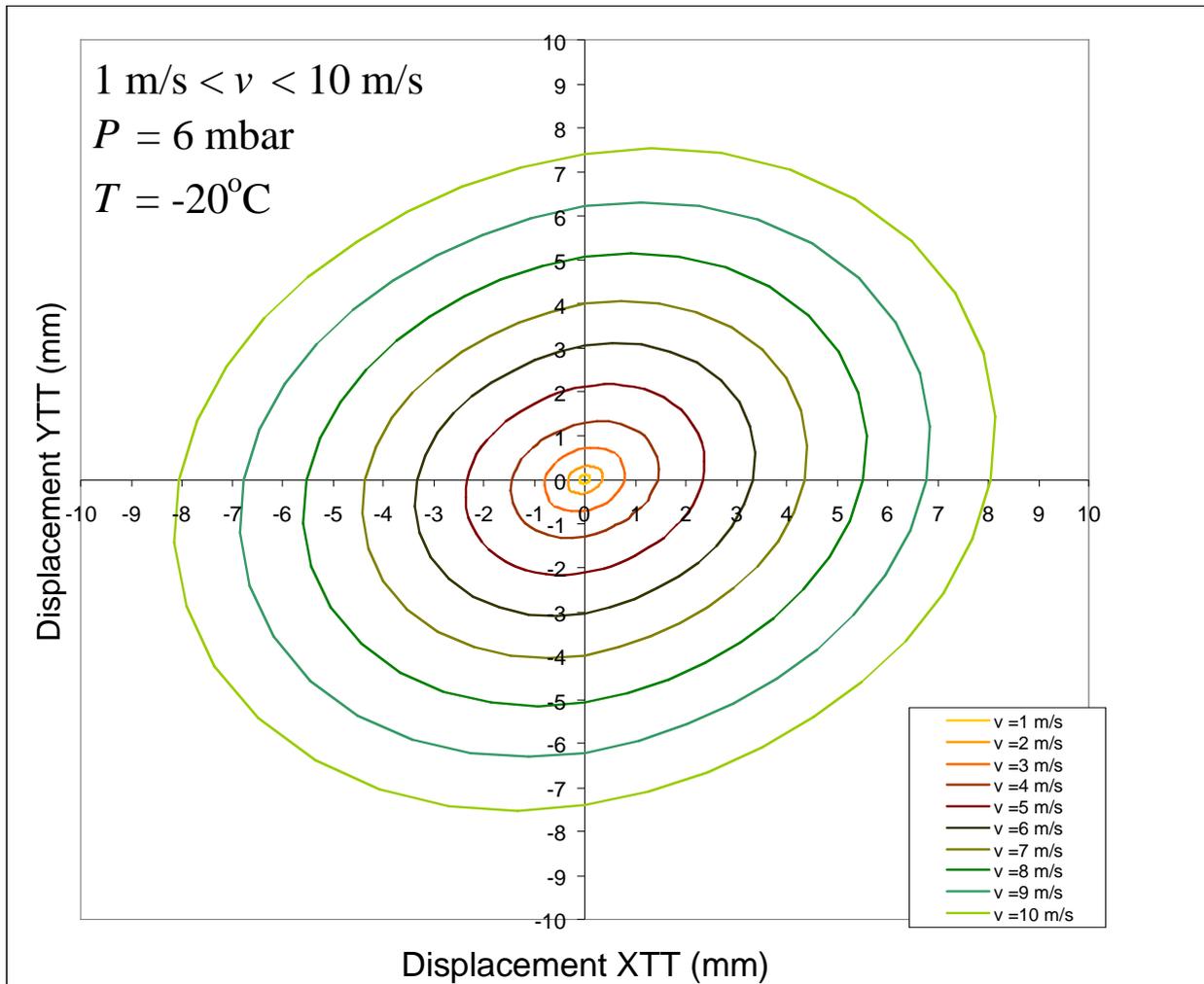
11 Error estimates and compliance with Payload requirements

The ECR #104074 (see "ECR_104074_Rev11.3.doc" of the Telltale EIDP (http://www.phys.au.dk/~hpg/EIDP/TT_EIDP.htm)) states the following:

> The payload shall be capable of measuring wind speed in two horizontal components: perpendicularly to the SSI camera line-of-sight over the range 1-10 m/s with accuracy of 1 m/s for winds of 1 to 5 m/s and of 20% for winds of 5 to 10 m/s; and along the SSI camera line-of-sight over the range of 2 - 10 m/s with accuracy of 2 m/s for winds of 2 to 5 m/s and of 40% for winds of 5 to 10 m/s.

There are 4 types of error contributions dealt with in this chapter. Most work has been done regarding the error in image analysis, mostly as this is the part we can do something about. The error contributions are summarized in the end. Upon request, a note from discussions with Mark Lemmon regarding contrast was added.

During the design phase of the Telltale, fluctuations at higher wind speeds were believed to be intrinsic properties belonging to generation of eddies at the end of the tube. Calculations performed by Carlos Lange, however, showed that these eddies would not contribute and the fluctuations were caused by turbulence, always presented in wind tunnel experiments.

11.1 Image errors

This part deals with errors originating from the analysis of the images from Mars. In the analysis two reference points are found: Centre of orientation marker in mirror image (*P*-0) and position of the tip of the screw (*P*-S). The position and orientation of the Kapton tube is found both from the direct (*P*-K) and mirror image (*P*-M).

These points are determined with sub-pixel accuracy. This is possible as the object fills out many pixels in the images. The determination of each error is based on the on-going analysis of Tilt Images. During this analysis, the program used for analyzing the images is constantly changing, as better ways to determine the points are found.
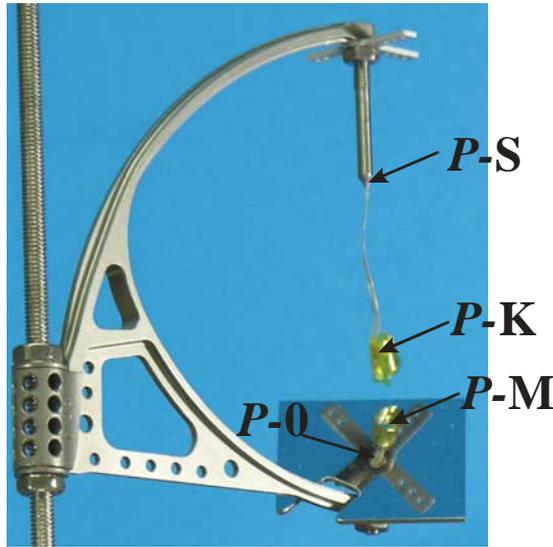
Fig. 33: Definition of points determined from the analysis.

Point	Error (pixels)	Notes
P-0	0.03	Included in version 1 of the ttmars program and tested. The centre of the orientation marker is well determined, as one has 9 points to determine its position.
P-S	0.1	Not thoroughly tested yet. Value obtained from version 1 of ttmars, values down to 0.05 should be achievable
P-K	0.07	Upper estimate. We will go for 0.05 in the next version of ttmars
P-M	0.07	Upper estimate.

As these are uncorrelated maximum errors, the error in the combinations, e.g. the shift of the Kapton tube perpendicular to the line of sight will be smaller. Here we see the Kapton tube from two directions enabling better determination of its position and as the shift in pixels is approximately *P*-K-(*P*-S+*P*-0)/2 the 1σ error in this shift is 0.029 pixels and total error (3σ) of ~0.087 pixels. The resolution of the Telltale is approximately 0.33 mm/pixel giving a total error of ~0.03 mm in determining the shift perpendicular to the line of sight. For the direction in the line of sight, we have only one determination of P-K, and expect the 1σ error to be 0.036 pixels and the total (3σ) error of 0.11 pixels. Using data from the analysis of the TiltImages the resolution in this direction is 0.34 mm/pixel (very different from the number derived from poor quality ORT8 images) giving rise to an error of 0.036 mm.

11.2 Zero wind position

The Zero wind position is assumed to be known within 0.1 mm (total) after landing. This number can and will be reduced with cross calibration with the TECP. Wind measurements with the TECP are done by measuring the cooling rate of one of the needles, but it has no directional sensitivity. The lowest cooling rate corresponds to the lowest wind velocity. Few simultaneous measurements with the TECP and Telltale should enable good correlation. Realistic goal is that this parameter will be known to 0.5 mm in each direction.

11.3 Lander tilt error

Based on information obtained during the Telltale CDR, the lander tilt will be known within 1°. The shift of the of the zero-wind position of the Kapton tube due to the Kevlar fibers stiffness is calculated using the Telltale model. As the shift is of the order 0.035 mm per degree of lander tilt this will results in inaccuracy of ~ 0.035 mm.

11.4 Calibration errors

The model used to describe the position of the Kapton part of the Telltale has been checked for consistency quite thoroughly. There are three contributions to its energy budget that have to be taken into consideration, 1) Gravity, 2) Kevlar stiffness and 3) Wind forces. The different calibration tasks described in this report depend on the estimates of these contributions in different ways. Tilt measurements measure the Kevlar stiffness relative to gravity. The analysis of the oscillation measurements included a gravity contribution that was shown to be consistent with estimates of mass distribution. Wind tunnel measurements depend on all contributions, and form the most reliable dataset.

The most probable error would be in the over/under estimate of Kevlar stiffness, correlated with an under/over estimation of the gravity contribution. This would not affect the wind tunnel data, and go unnoticed. However, when scaling to Mars gravity, this inconsistency causes problems.

Experimenting with the parameters obtained (increase of $A_K^{(1)}$ and decreasing a) to obtain the same deflection curve under Terrestrial conditions can result in 5% difference in Martian curves. Restricting the variation in $A_K^{(1)}$ and decreasing a to hold at all pressures where the Telltale was calibrated (8-20 mbar), lowers this maximum error contribution to 3%. Change of other parameters such as C_1 leads to smaller errors. Taking all this into consideration, we put a "flat" 10 percentage error on the whole range.

Image contrast

The following notes come through discussion with Mark Lemmon. To obtain a usable picture one needs to see the Kapton part relative to the background sky. Sky brightness depends greatly on dust amount, of course. For expected dust amounts, the sky is significantly brighter than the ground at 440 nm; the Kapton is significantly darker than the ground at 440 nm. That is amplified if there is water ice.

If the sky were too dark, we'd get tons of contrast by switching to 750 nm, albeit with shorter exposures.

11.5 Summary

Error source	Value (in line of sight)	Value (perpendicular to line of sight)
Image analysis	0.035 mm	0.033 mm
Zero position	0.05 mm	0.05 mm
Lander tilt	0.035 mm	0.035 mm
Calibration errors	10%	10%

The errors above are either given in mm of determining the position of the Kapton tube or percentages of the wind speed. To obtain a relative measure, the model of the telltale has been applied

with P = 8 mbar and T=-60°C to find the wind related.deflection and the comparison presented in Fig. 34 was generated.
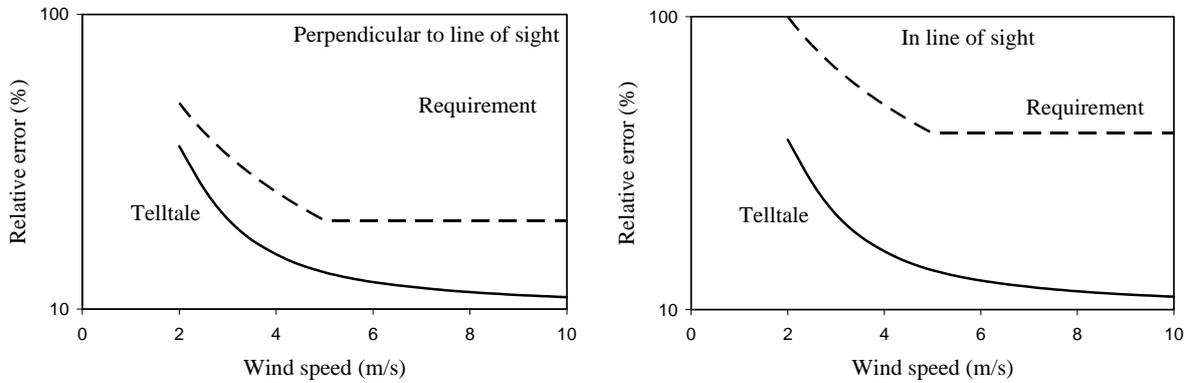
Fig. 34: Relative error in the determination of the Kapton part of the Telltale compared to the requirements.

In both cases, the Telltale determines winds with accuracy better than the requirements. How much better the Telltale can derive wind information will be re-evaluated using the results from the analysis of Tilt Images.

12 Telltale user manual

12.1 Introduction

The following pages describe the programs used to get wind information from the Telltale. IDL is used to obtain the relevant image coordinates that are needed, and further analysis is made in Excel. Many aspects of the data reduction have not been finalized. The description below describes the first version of the program ttmars, that was available during ORT8.

12.2 IDL analysis

Run the idl program "ttmars". The program has been tested on PCs running IDL 6.4 and 6.3. The following picture should come up.
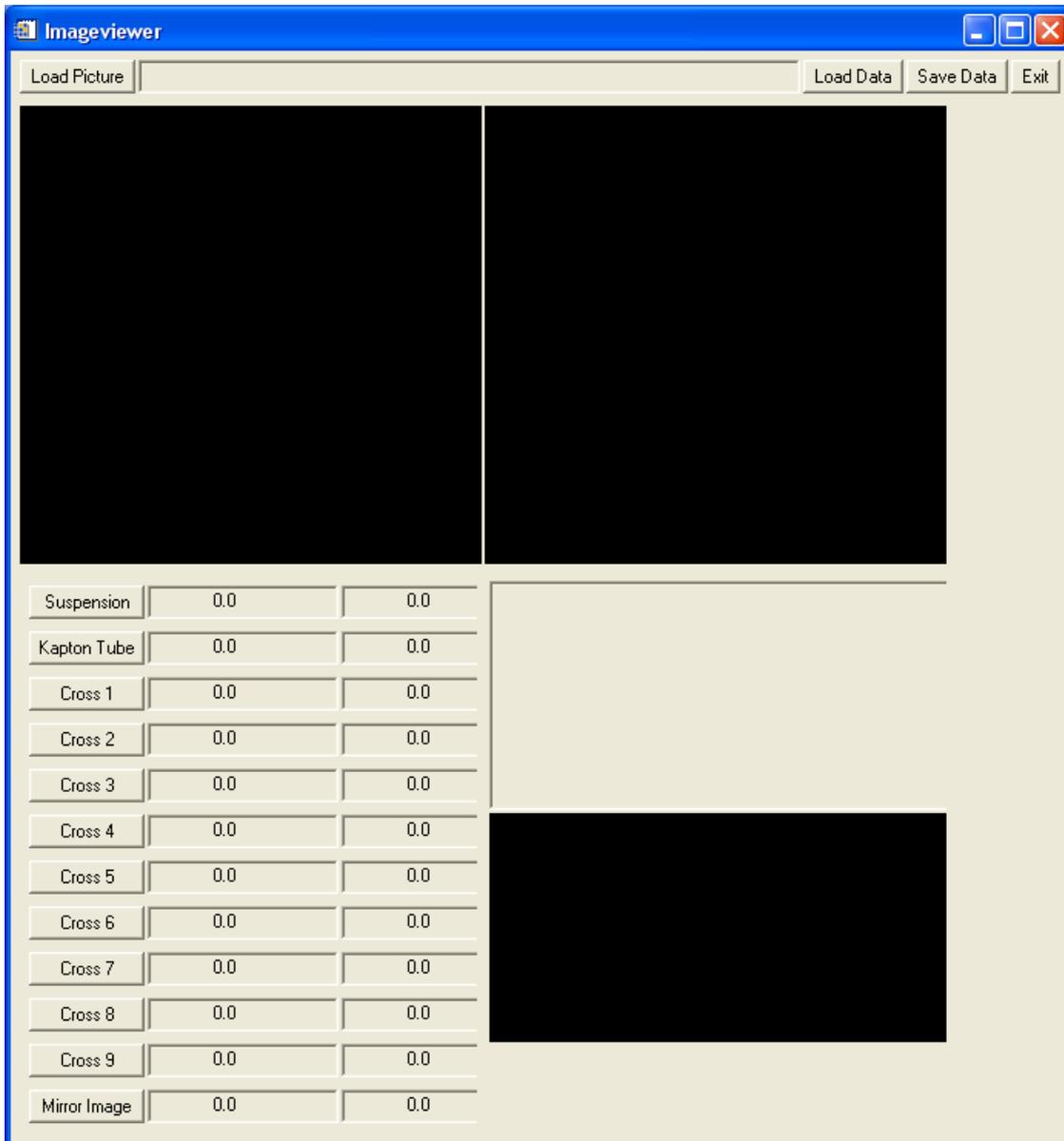
Fig. 35: Window that comes up when "ttmars" is run

At the top, one can load a new picture, save the data when finished or simply exit the program. It is also possible to load any data (image coordinates) saved for that image. The top two windows are for the original image (left) and the zoomed image (right). Having opened an image the following picture comes up:
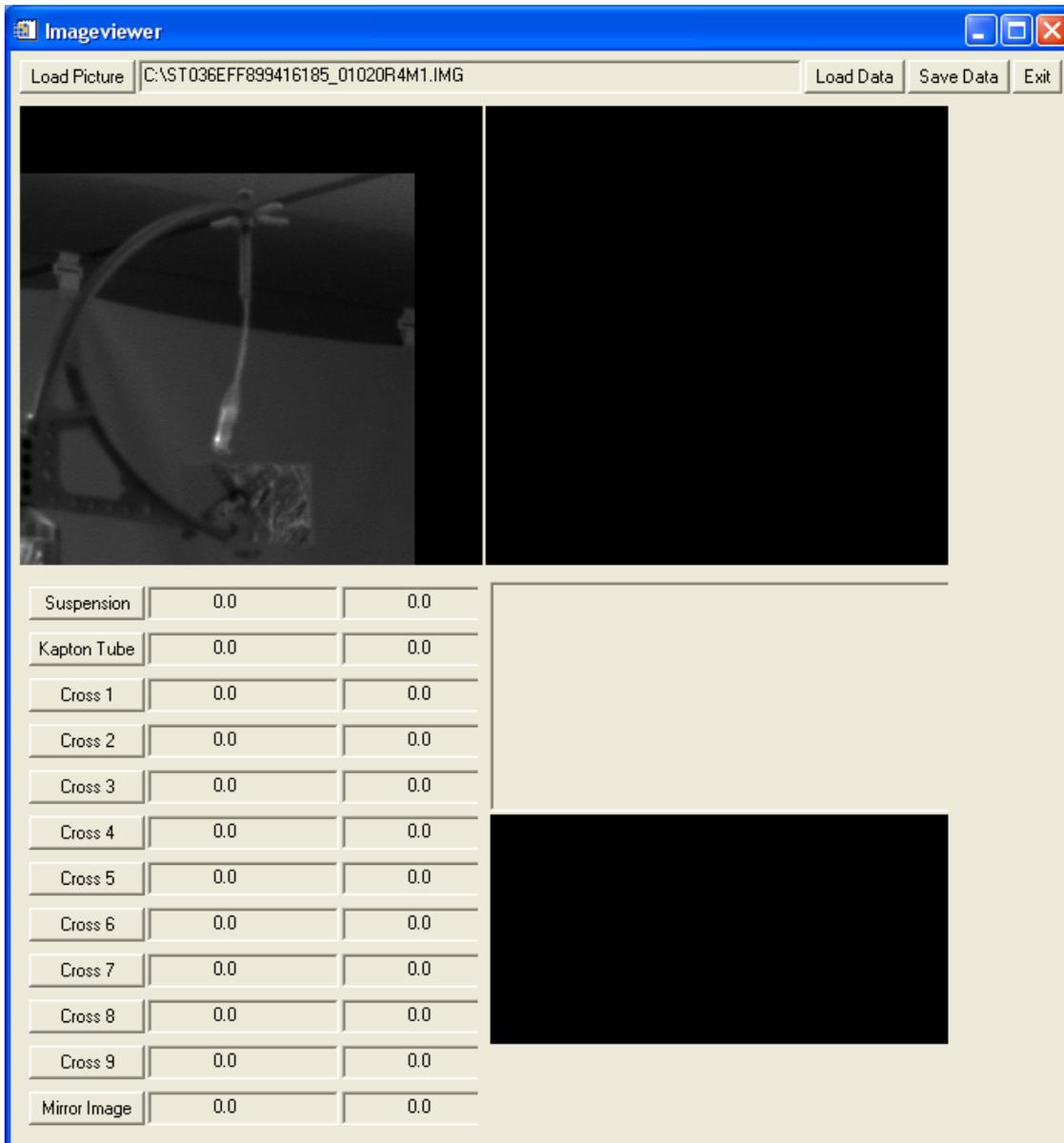
Fig. 36: Window that comes up after image has been read into imageviewer.

The image displayed is not scaled in this version, and ORT images can appear a bit dark due to saturation.

The buttons below the image list the coordinates that have to be selected. Suspension is the definition of where the fibres are hanging from the screw, the Cross points are the coordinates of the hole pattern in the cross, and two buttons are taken for the definition of the Kapton Tube in the direct image and in the mirror image. Selecting *e.g.* Cross 6 point, one should click the image to obtain a magnified image, and clicking on the magnified image will give the coordinates of the clicked point in image coordinates in the text boxes beside the buttons. The third image field displays an explanation of how this should be done.
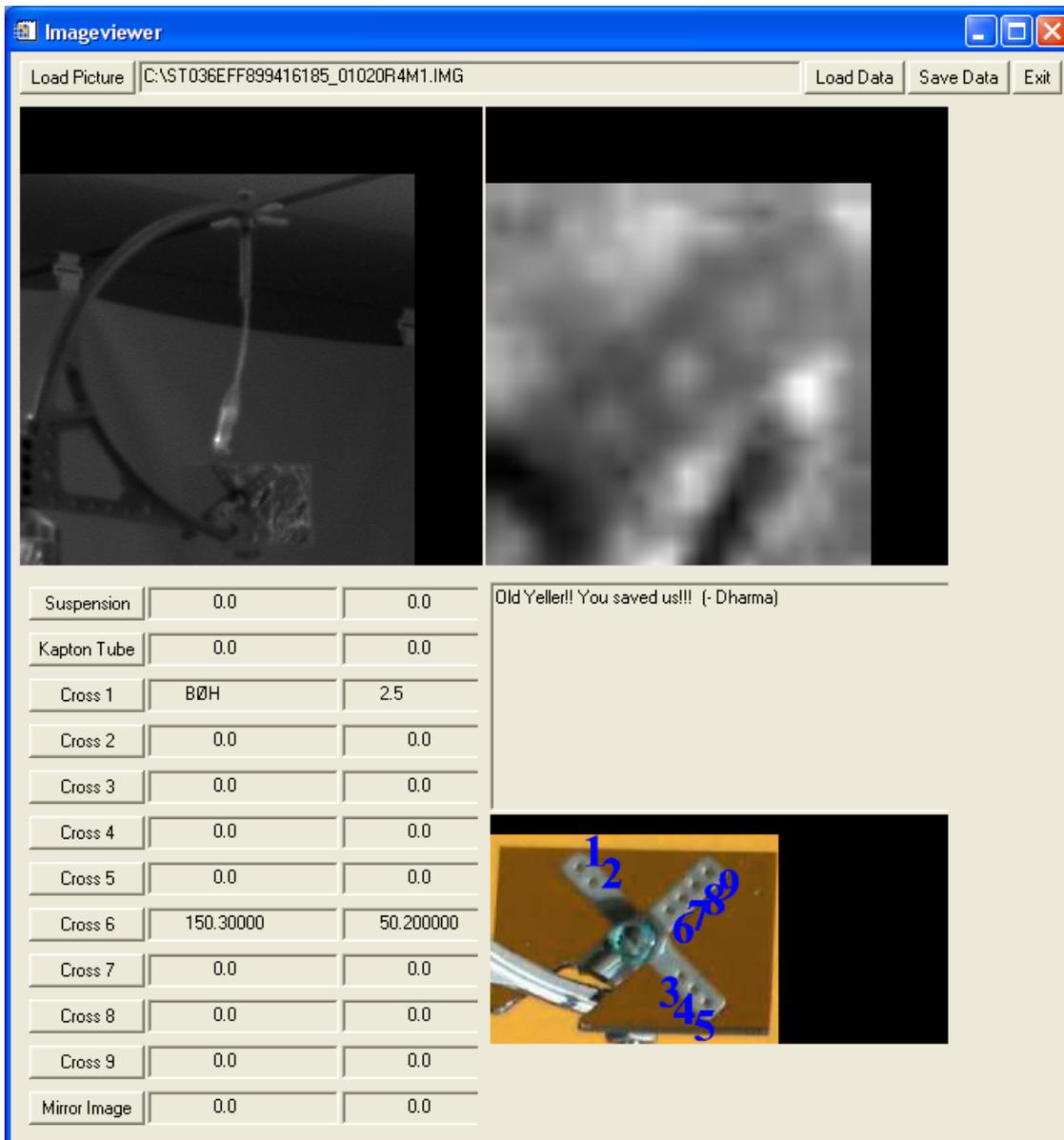
Fig. 37: Window that comes up when Cross 6 has been selected and one has made a click on the original image.

When all coordinates have been selected, the data is stored, and this stores a txt file in the same folder as the original image.

12.3 Excel analysis part 1

The excel analysis is divided into two phases. 1) Getting real coordinates of the Kapton tube from the image points selected in the IDL analysis and 2) using the calibration to obtain wind velocity.

The file "GetData.xls" is set up with macros to get the data out (downloaded). It contains the macro "GetData" that reads in a .txt file generated with IDL and reads the data in for processing. The following data is seen:

The light-green numbers are the numbers that are read in, and are furthest to the right with calculations. The yellow numbers are those that have to be optimized (using the Excel built-in function Solver. This uses the cross to get the scale of the mirror image (Resx and Resy), centre of the cross (origo_x and origo_y) along with the image rotation of the Cross.

From these numbers, some additional numbers are calculated (orange), the real shift of the Kapton part (tt_x and tt_y) is the most important (others are for debugging purposes).

12.4 Excel wind analysis (part 2)

The last part of the analysis is to use the shift values to obtain wind information.
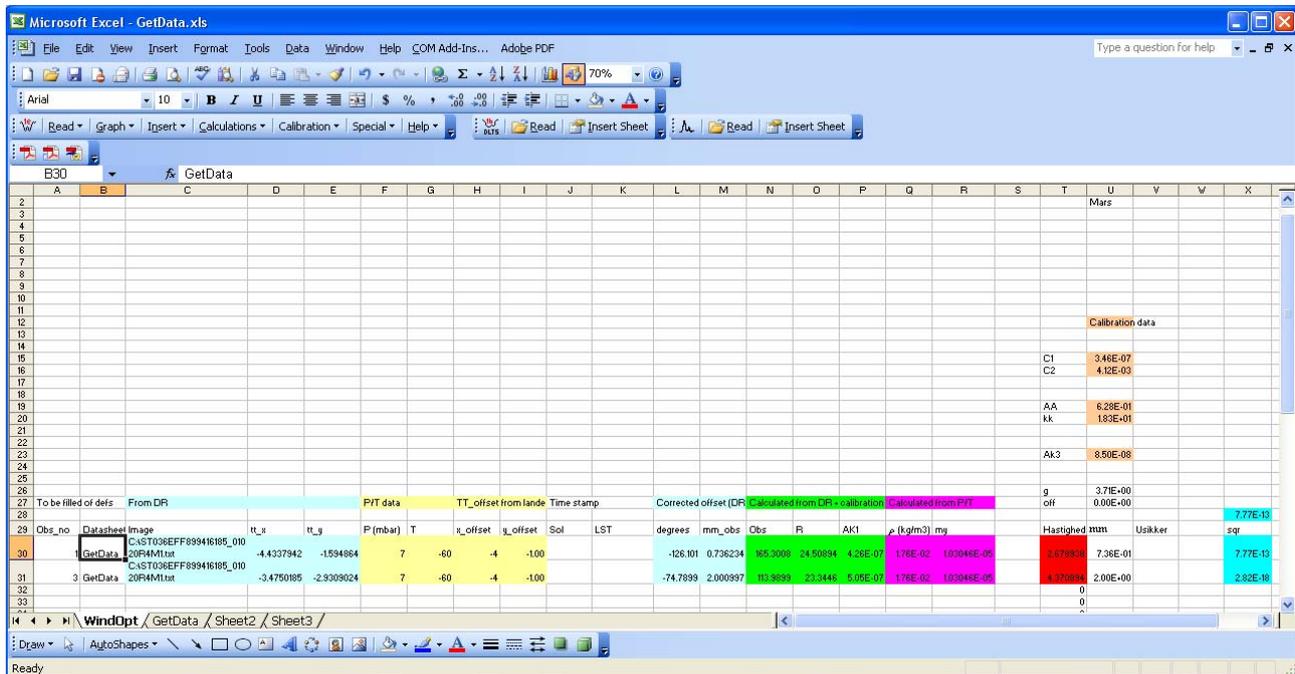
A color scheme is used to help figuring out the numbers. An explanation is given below:

Columns:	Description
A-B	Label indicating which row of the reduced data are used. In this case observations no. 1 & 3 in the "GetData" sheet
C-E	Values extracted from the data reduction
F-I	External data that has to be filled in each time. This includes the temperature and pressure together with Telltale offset based on lander tilt and calibration results.
J-K	Time stamp, It should be possible to figure this out from the filename, but the routines have not been written yet.
L-M	Calculated shift of the Kapton part of the Telltale
N-P	Orientation dependent calibration constants. Obs. Orientation is the orientation in the calibration coordinates.
Q-R	Pressure and temperature dependent constants
T	wind velocity output obtained (has to be optimized using Solver)
U	Calculated shift of Telltale (based on input)
X	Square difference of the observed TT shift and the actual shift. These values should be minimized by changing the values in the T column with Solver

13 Appendix: Conversion of LTST to LMST using CHRONOS data

The online time converter, CHRONOS[1], was used to set up a list of LTST versus LMST times for the duration of the Phoenix mission (see Table 1). The value of LTST-LMST was calculated and a 6th degree polynomial was fitted to those numbers. The result was an equation for calculating LMST throughout the Phoenix mission with a precision of less than 0.5 seconds:

$$LMST = LTST - \sum k_i * (LTST/150)^i$$

$k_0 = 0.009271037$
$k_1 = 0.020473743$
$k_2 = -0.016543145$
$k_3 = 0.013583908$
$k_4 = 0.001171538$
$k_5 = -0.002503976$
$k_6 = -0.000623474$

Table 1: List of obtained LTST/LMST times from Chronos.
 PHX_OPS080526: sol 0 12:00:00 (LST/LTST) --- SOL 0 11:46:33 (LST/LMST)
 PHX_OPS080526: sol 10 12:00:00 (LST/LTST) --- SOL 10 11:44:42 (LST/LMST)
 PHX_OPS080526: sol 20 12:00:00 (LST/LTST) --- SOL 20 11:43:01 (LST/LMST)
 PHX_OPS080526: sol 30 12:00:00 (LST/LTST) --- SOL 30 11:41:28 (LST/LMST)
 PHX_OPS080526: sol 40 12:00:00 (LST/LTST) --- SOL 40 11:40:02 (LST/LMST)
 PHX_OPS080526: sol 50 12:00:00 (LST/LTST) --- SOL 50 11:38:41 (LST/LMST)
 PHX_OPS080526: sol 60 12:00:00 (LST/LTST) --- SOL 60 11:37:21 (LST/LMST)
 PHX_OPS080526: sol 70 12:00:00 (LST/LTST) --- SOL 70 11:36:02 (LST/LMST)
 PHX_OPS080526: sol 80 12:00:00 (LST/LTST) --- SOL 80 11:34:42 (LST/LMST)
 PHX_OPS080526: sol 90 12:00:00 (LST/LTST) --- SOL 90 11:33:21 (LST/LMST)
 PHX_OPS080526: sol 100 12:00:00 (LST/LTST) --- SOL 100 11:31:56 (LST/LMST)
 PHX_OPS080526: sol 110 12:00:00 (LST/LTST) --- SOL 110 11:30:28 (LST/LMST)
 PHX_OPS080526: sol 120 12:00:00 (LST/LTST) --- SOL 120 11:28:57 (LST/LMST)
 PHX_OPS080526: sol 130 12:00:00 (LST/LTST) --- SOL 130 11:27:22 (LST/LMST)
 PHX_OPS080526: sol 140 12:00:00 (LST/LTST) --- SOL 140 11:25:46 (LST/LMST)
 PHX_OPS080526: sol 150 12:00:00 (LST/LTST) --- SOL 150 11:24:10 (LST/LMST)

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[1] http://naif.jpl.nasa.gov/cgi-bin/chronos_phx.pl?setup=phxtime