S.P. Schneider, Purdue University, School of AAE, 765-494-3343, 30 June 1999
Measurements by Chris Tieche, Purdue University, School of AAE.

Note: This document is best accessed as a Word file, since the images are in color, and the original electronic version allows magnified views of the images.

Zygo Optical Profilometer Measurements of Test Mandrel: Sample Tests for Mach-6 Quiet-Flow Nozzle Throat

1. Introduction

The mandrel and electroformed throat are critical sections of the Purdue Mach-6 quiet-flow Ludwieg tube. The largest flaw in the mirror finish of the throat controls performance. NASA Langley fabricated many quiet-flow nozzles during 1972-1994, many of which suffered from problems with waviness and roughness in the throat. These problems were often large enough to make the nozzles useless. Eventually the technique of electroforming nickel onto a polished mandrel was developed. This was used successfully for the LaRC Mach-6 quiet-flow nozzle ca. 1990. The electroform is supposed to reproduce the finish of the mandrel, and it is much easier to polish on the outside of the mandrel. However, the initial performance of the LaRC Mach-6 apparently degraded after initial operation, possibly because of surface degradation in the throat associated with hot operation. Since the initial data is not conclusive, according to Steve Wilkinson, the true cause of the apparent degradation is unknown.

Low-cost and simple tests of this hot-operation degradation were desirable, in order to reduce risk. In addition, the Purdue nozzle is to introduce the use of a hard layer of electroformed nickel, approximately 1/8-inch thick, on the surface near the mandrel. Both the hard and soft nickel are nearly pure, and prepared from a sulfamate bath by GAR, the same vendor used for the LaRC Mach-6 nozzle. The hard nickel bath differs only by the addition of trace amounts of saccharin. This hard nickel, Rc33-35-38, should be much more scratch-resistant than the soft nickel used in the LaRC nozzle (Rc 21-23). However, this also introduces concerns about cracking, delamination, or other problems with the hard nickel.

Samples of the hard and soft nickel were therefore procured from GAR, and tested, as outlined in previous memos and emails. These earlier samples were plated onto glass or aluminum plate substrates that were provided by GAR. The surface finish of one sample degraded markedly after heating, while the others appeared unaffected (see previous memos). This sample was plated onto glass, after the glass was sprayed with silver to make it conductive. After the sample was removed, the silver was removed with an alkaline solution. This differing surface treatment may have accounted for the degradation. A 6x6 coupon of layered hard and soft nickel was also tested, and did not bend while hot, indicating matched thermal expansion coefficients; no delamination tendencies were observed either.

However, because these tests were inconclusive, particularly regarding the surface finish, the fabrication of a test mandrel was deemed desirable. A drawing of the test mandrel is shown as Figure 1. The fabrication and electroforming are to duplicate the process used for the real mandrel, to the extent feasible, using a small scale for low cost. The mandrel was fabricated at Purdue by Lester Cox, and heat treated at Circle-City heat treat. This memo reports

measurements of the surface finish carried out at Purdue, following polishing of the mandrel at Optical Technologies. Later memos will report results for the electroform.

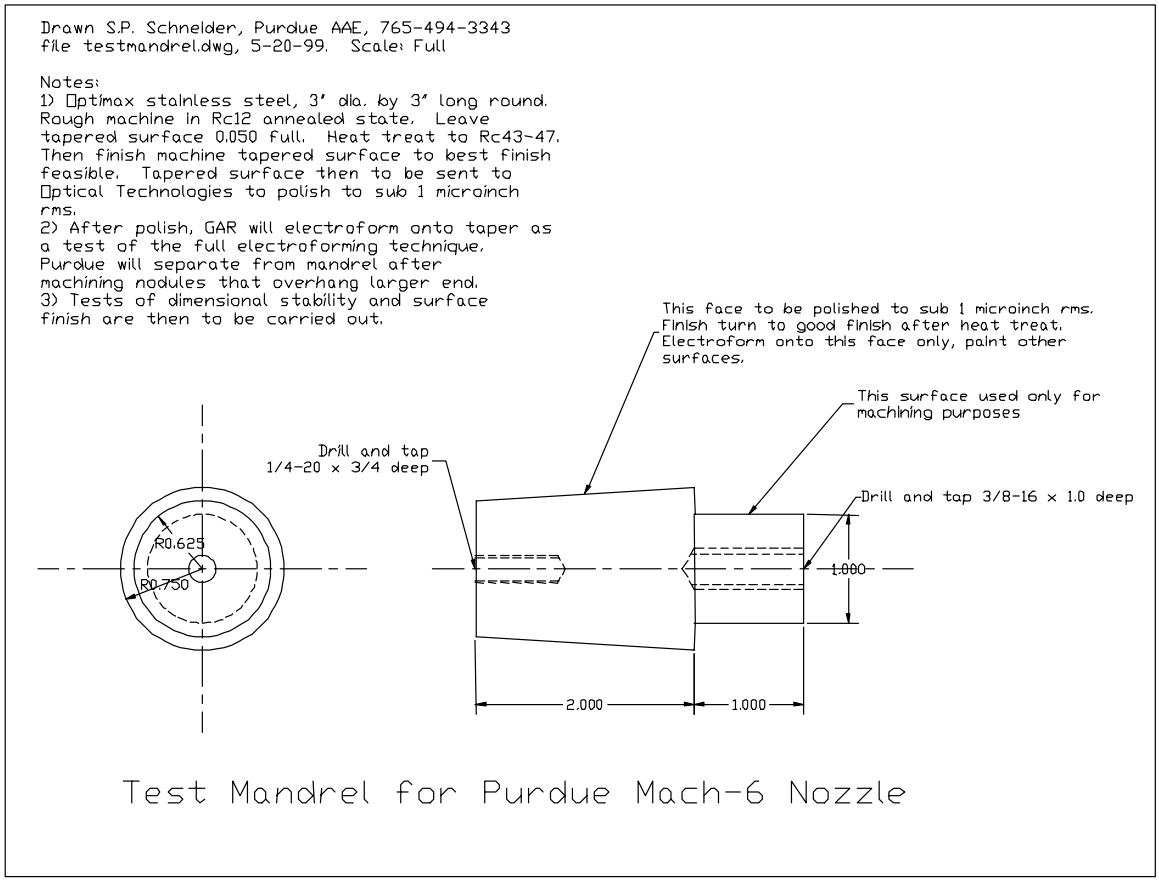

Figure 1: Drawing of Test Mandrel

2. Optical Profilometer Measurements

Chris Tieche carried out measurements on the specimen using the Zygo optical profilometer at Purdue, and provided a set of .bmp files, along with an emailed summary (appended). This section presents his results. Chris is a graduate student in tribology who works under the direction of Prof. Tom Farris.

Chris took 10 measurements for the surface using the optical profilometer, for 10 sample areas. Since getting raw data out of this instrument has not been successful, he supplied some data that represents the material in the output files. These were supplied as .bmp files. Chris commented that *"Sample sizes were 0.08mm squares (as shown). I used a 50x/0.5x combo lens with a cylinder remove baseline. Overall, these samples were pretty good. The waviness of the surface may be a concern for you, though."*

Figure 2 shows the surface image of the first area selected. These are the top and oblique views. The values of Ra and RMS are shown on the figure in nanometers. Note that Ra is 0.36 microinches, a very low value.

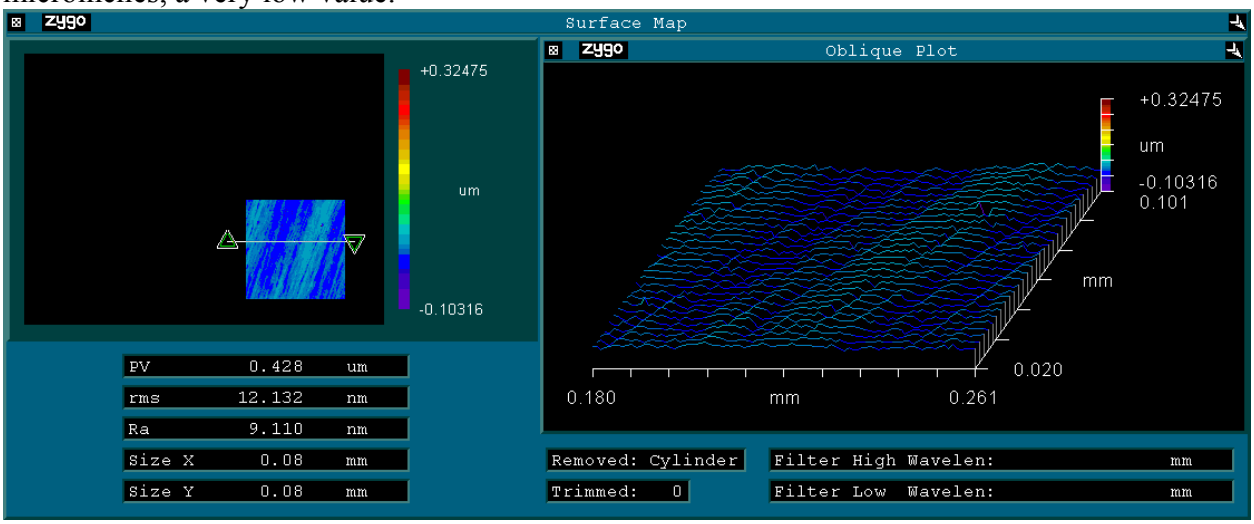

Figure 2: Surface Contours, Area 1

Figure 3 shows the surface profile along the yellow line shown in the top view (left-hand side) of Fig. 2. Note that 50 nm peak-peak is 2 microinches peak-peak, an excellent value. The nozzle design calls for a peak roughness height of about 90 microinches or less, in the throat; it was assumed that this corresponds to an rms roughness of about 3 microinches or less.

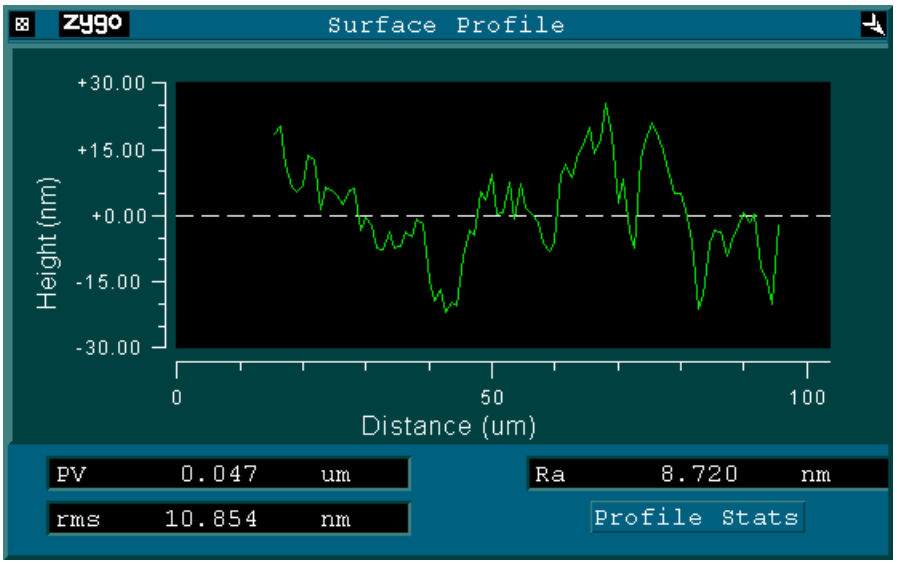

Figure 3: Surface Profile for Area 1

Figures 4 and 6 show the top and oblique views for areas 2 and 3, while Figures 5 and 7 show the corresponding surface profiles. The values of Ra are similar, or a little higher, and there are no distinguishing characteristics. The roughness looks like streaks or scratches from the polishing.

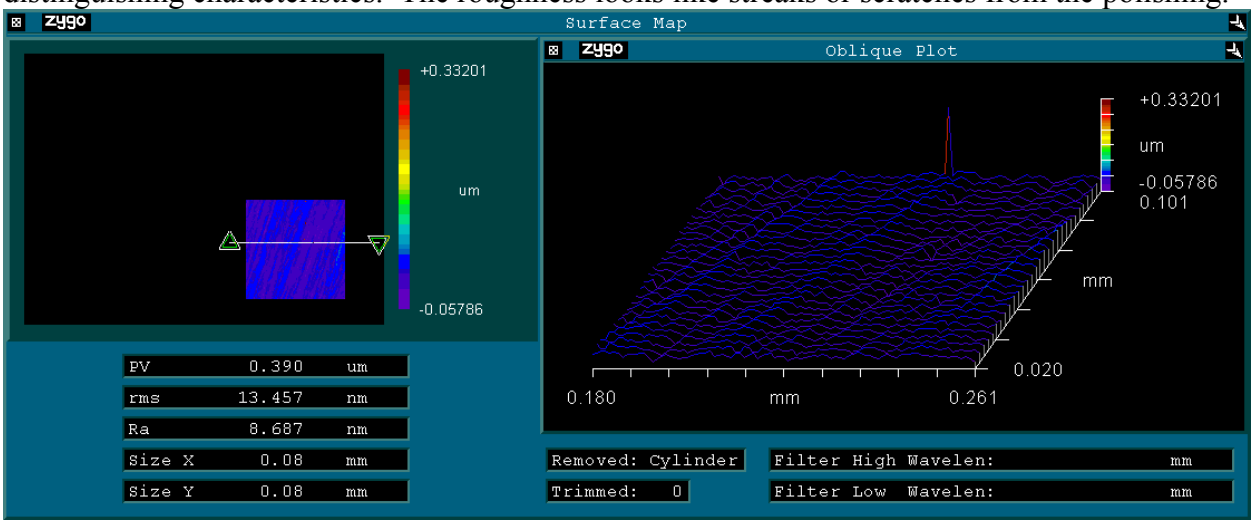

Figure 4: Surface Plot, Area 2

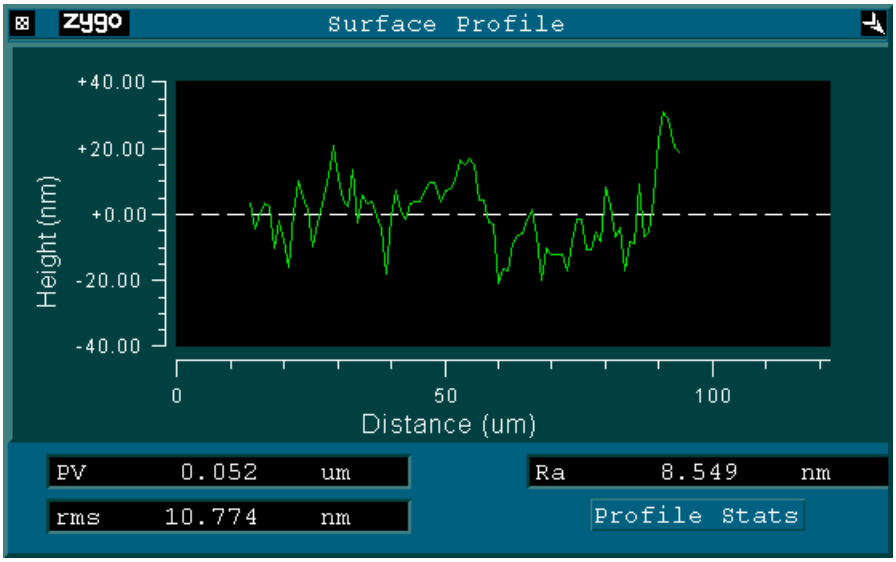

Figure 5: Surface Profile, Area 2

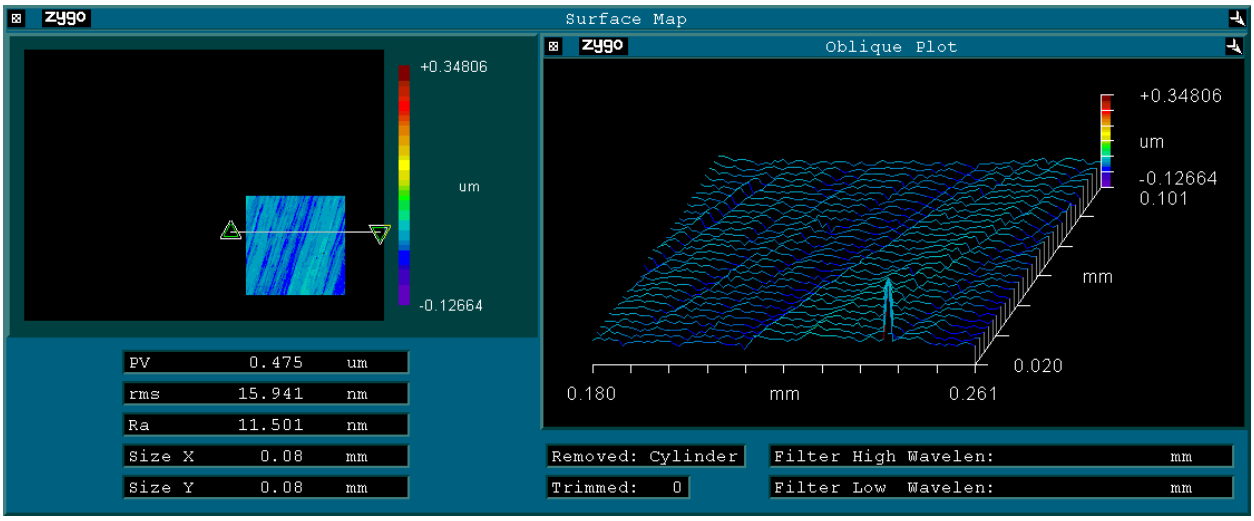

Figure 6: Surface Plot, Area 3

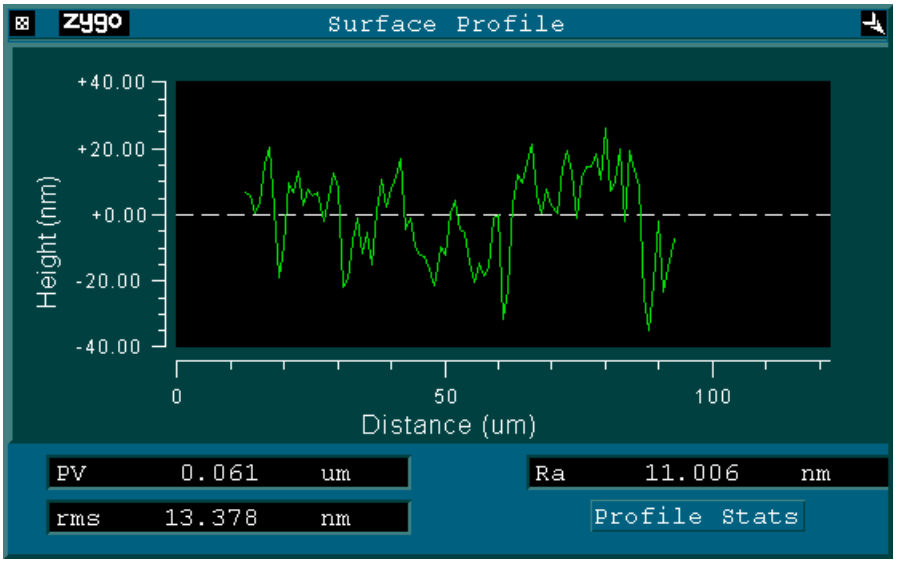

Figure 7: Surface Profile, Area 3

Figures 8, 10, and 12 show the surface plots for areas 4, 5, and 6. Figures 9, 11, and 13 show the corresponding selected surface profiles. According to Chris, *"There definitely is a "waviness" of regular frequency on the surface (see oblique plots). In many cases, left hand side of 04, RHS of 05 and 06, relatively deep grooves are visible, maybe a resultant from a turning process. These grooves were typically 60nm* [2.4 microinches*] deep. Typical peak to peak values were around 50nm* [2.0 microinches] *(see surface profile plots for typical profiles) for all the scans."*

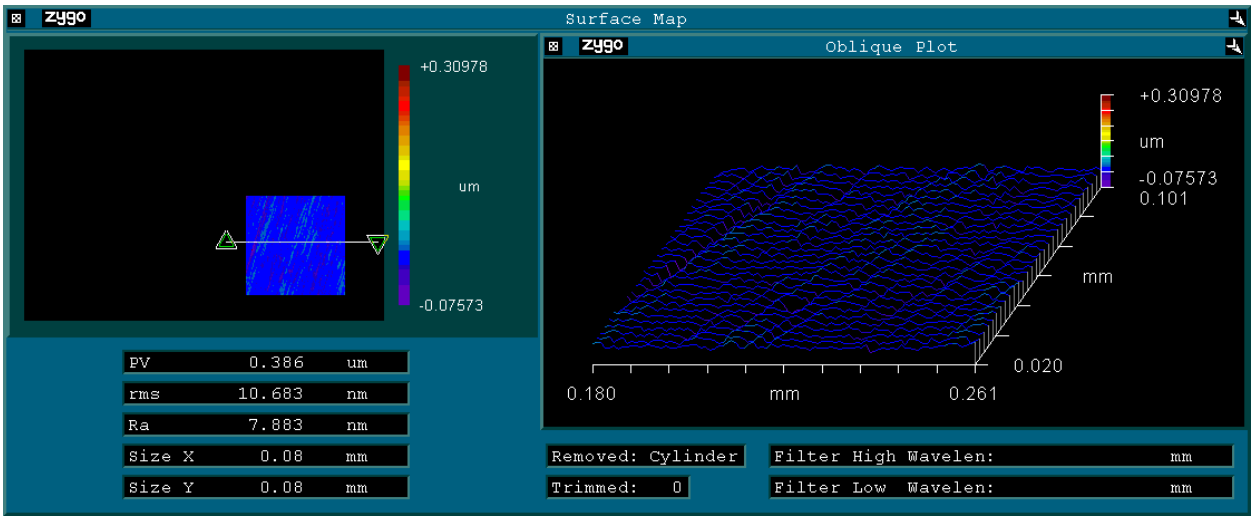

Figure 8: Surface Plot, Area 4

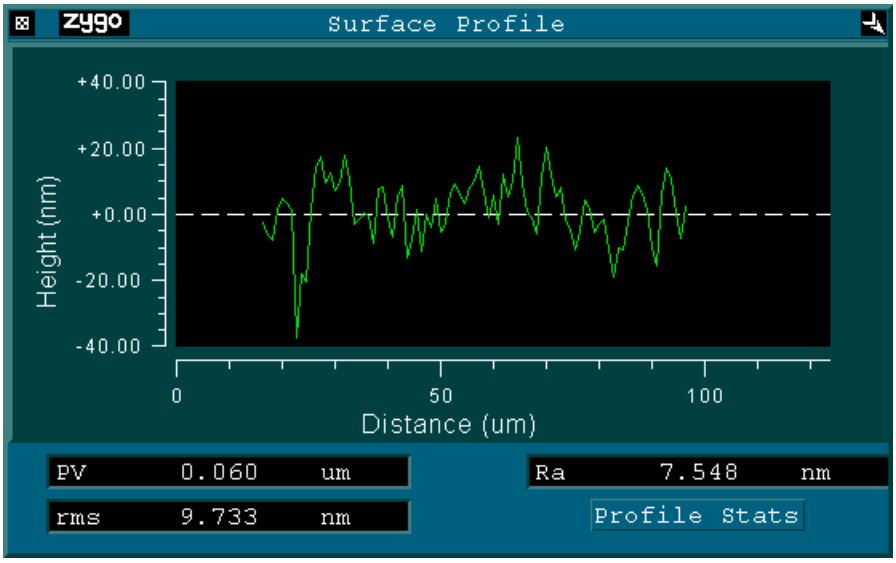

Figure 9: Surface Profile, Area 4

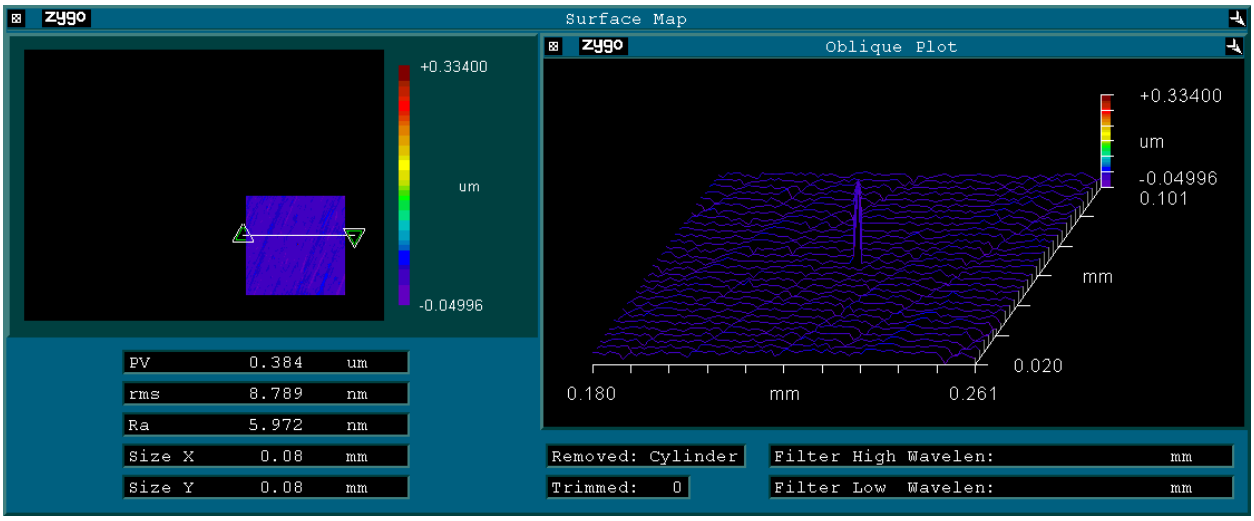

Figure 10: Surface Profile, Area 5

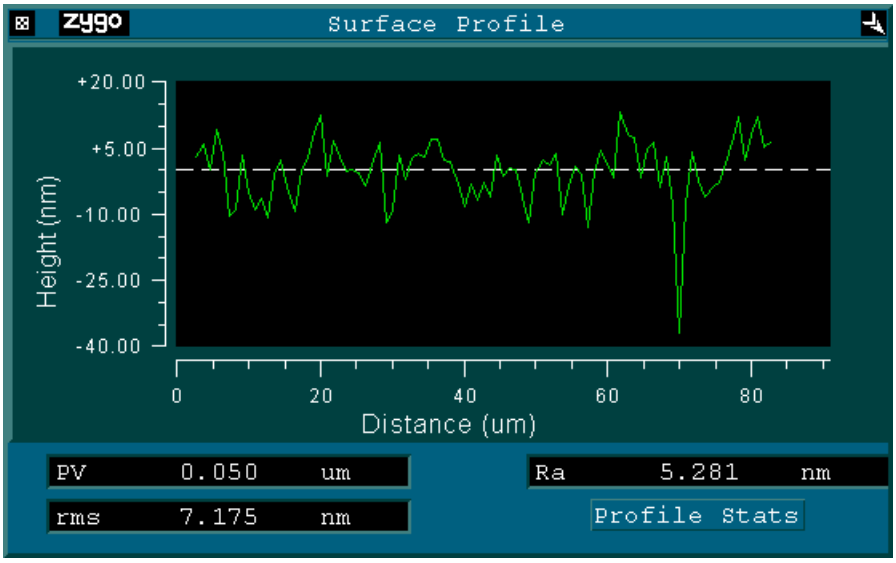

Figure 11: Surface Profile, Area 5

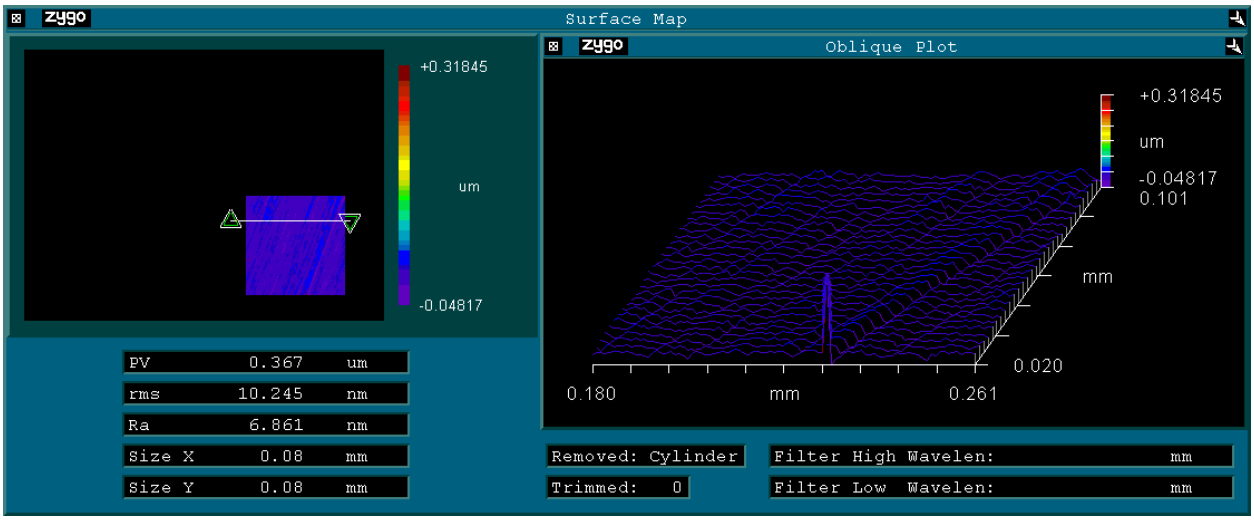

Figure 12: Surface Plot, Area 6

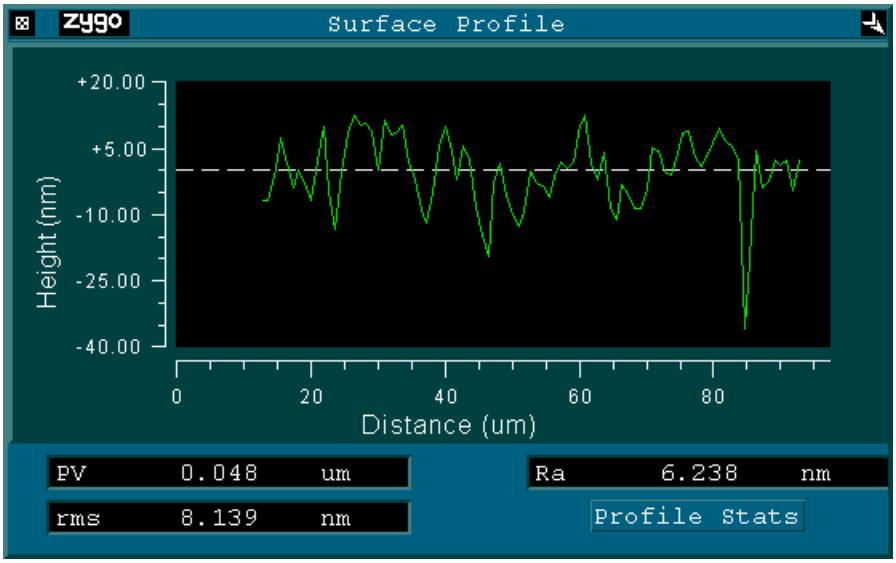

Figure 13: Surface Profile, Area 6

Figure 14 shows the surface plot for area 7, while Fig. 15 shows the corresponding selected profile. According to Chris, *"07 has several short peaks -- I think this is because of dust or outside light. Measuring artifacts are typically single point spikes and can be ignored (though they do make a very small contribution to RMS and Ra). These are visible in many of the scans (07 included) and can be attributed to dust, or reflected ambient light (which becomes a source of concern if the user is not careful with such a reflective sample). Spikes, as in 07, moved around from scan to scan, so I don't think they are surface features."*.

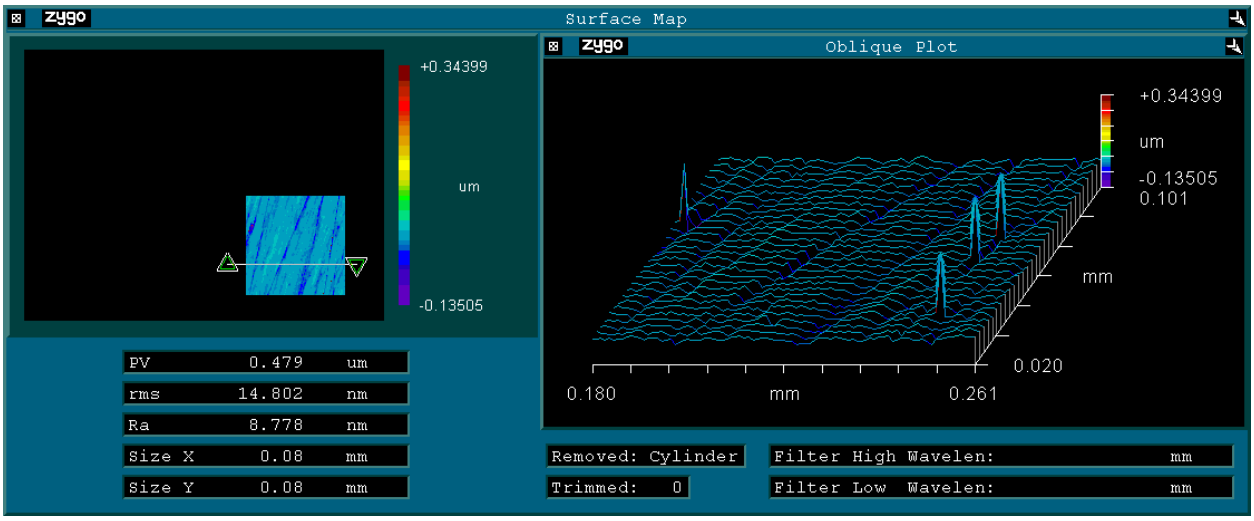

Figure 14: Surface Plot, Area 7

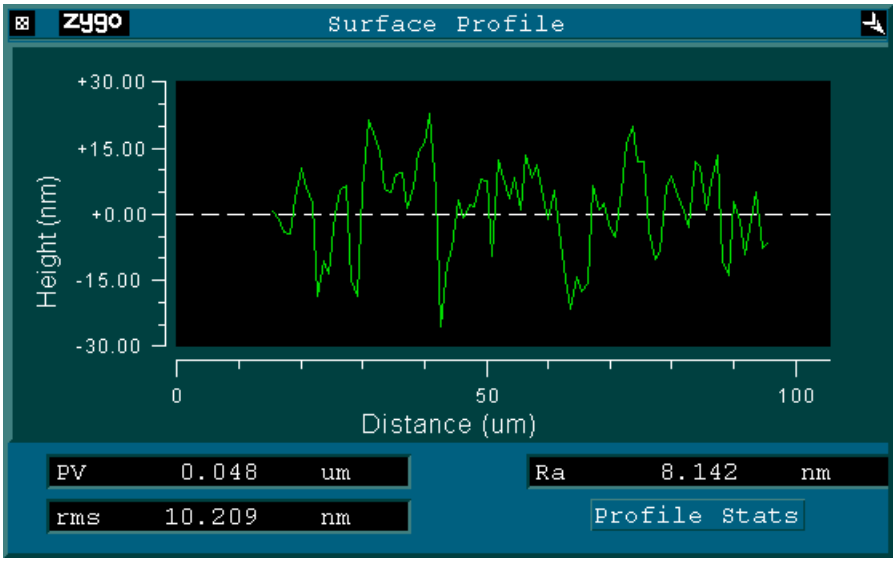

Figure 15: Surface Profile, Area 7

Figure 16 shows the surface plot for area 8, while Fig. 17 shows the corresponding profile. According to Chris, *"08 had a pocket of deep pits. Because of the grouping, I don't think this is an artifact -- I think it is a surface feature. The scope read 600nm [24 microinches] deep, but for topography that deep and narrow, that might not be entirely accurate. It is probably 300+ nm for sure, and I say that because I made repeated scans and there was some variability to the depth (350 to 600 nm). RMS and Ra still were not affected much by this variation, though, compared to other scans, the values are probably still high."* This pocket of deep pits can be seen more clearly in Fig. 18, which is a detail of the surface plot of Fig. 16, magnified by 10 times by expanding the .bmp image. The horizontal line in Fig. 18 is the line across which Fig. 17 is plotted. It is nearly centered on one of the larger pits. The image is 0.08mm or 0.0032 inches on a side (cp. the oblique view of Fig. 16).

According to Chris, the whole surface appeared perfect to him, by eye. Only under the Zygo were the small defects visible. The 10 images are therefore random samples from different points around the polished surface. Only area 8 shows these 4 pits. Defects were sometimes apparent under the Zygo, but these are often due to lighting or dust. In any cases where defects were apparent, Chris would repeat the measurement with a slight translation, and see if the defect showed up in the same place. Only when the measurement was repeatable did Chris believe it to be reliable, to show an actual defect in the material. These pits in area 8 are the only large defects which he believes are actually in the material.

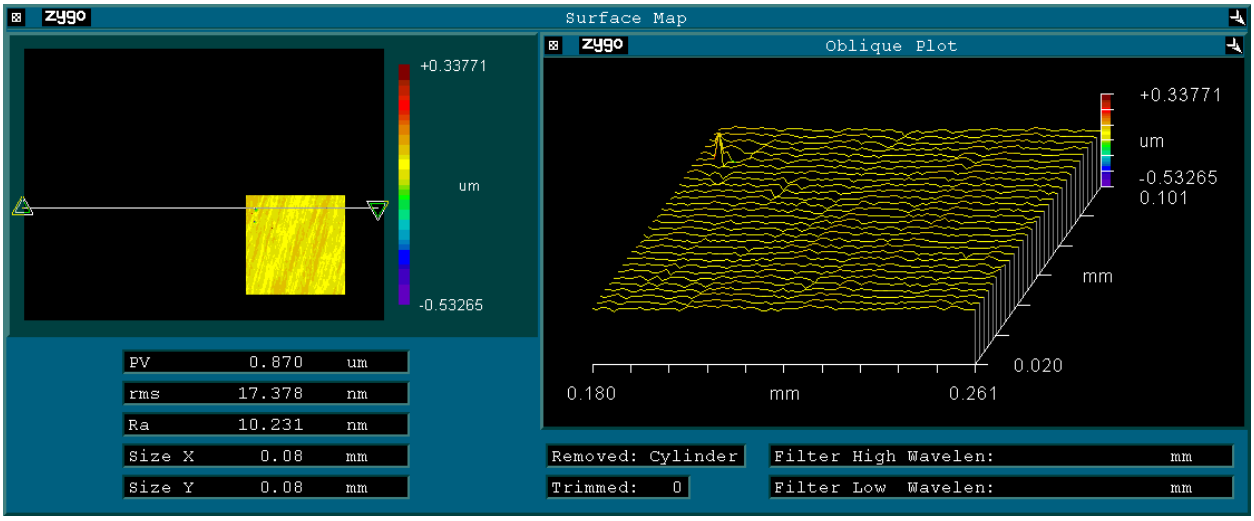

Figure 16: Surface Plot, Area 8

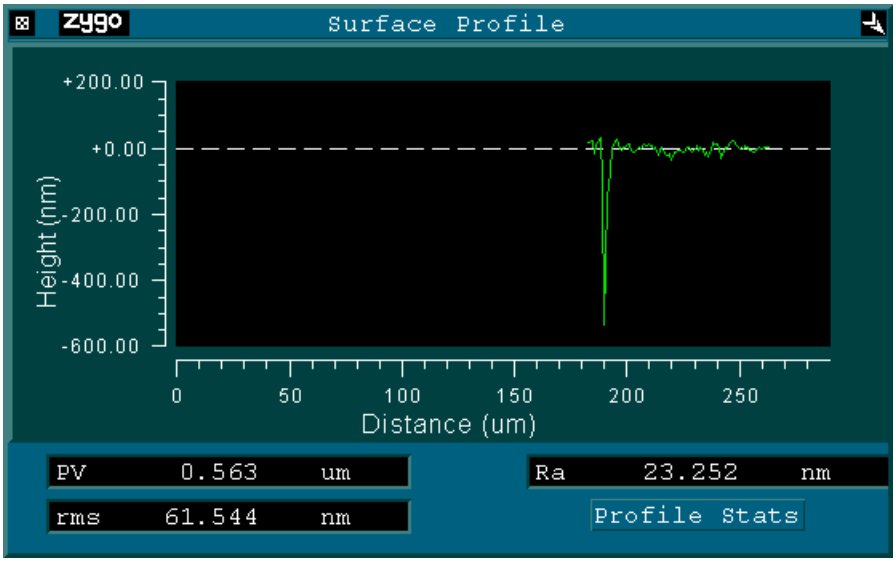

Figure 17: Surface Profile, Area 8

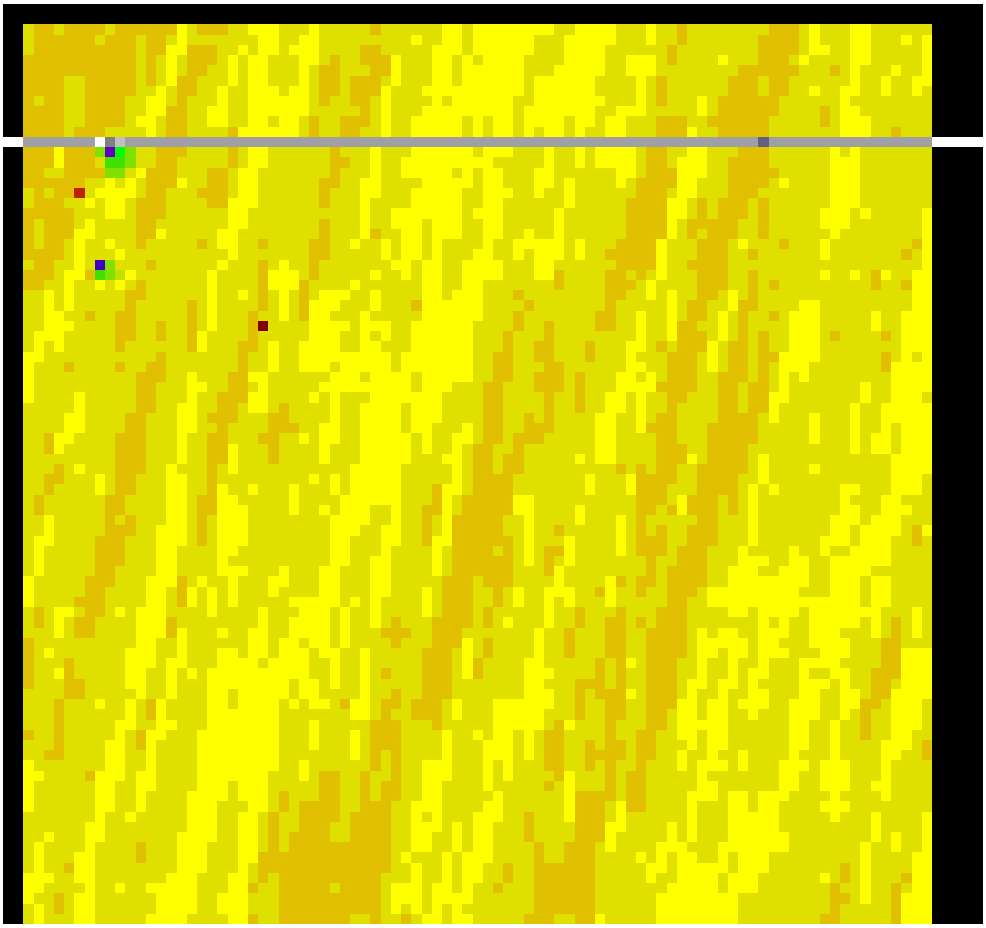

Figure 18: Detail of Surface Plot, Area 8, Showing 4 Pits in Upper Left, 2 Large and 2 Small.

Figures 19 and 21 show the surface plots for areas 9 and 10, and Figures 20 and 22 show the corresponding surface profiles.

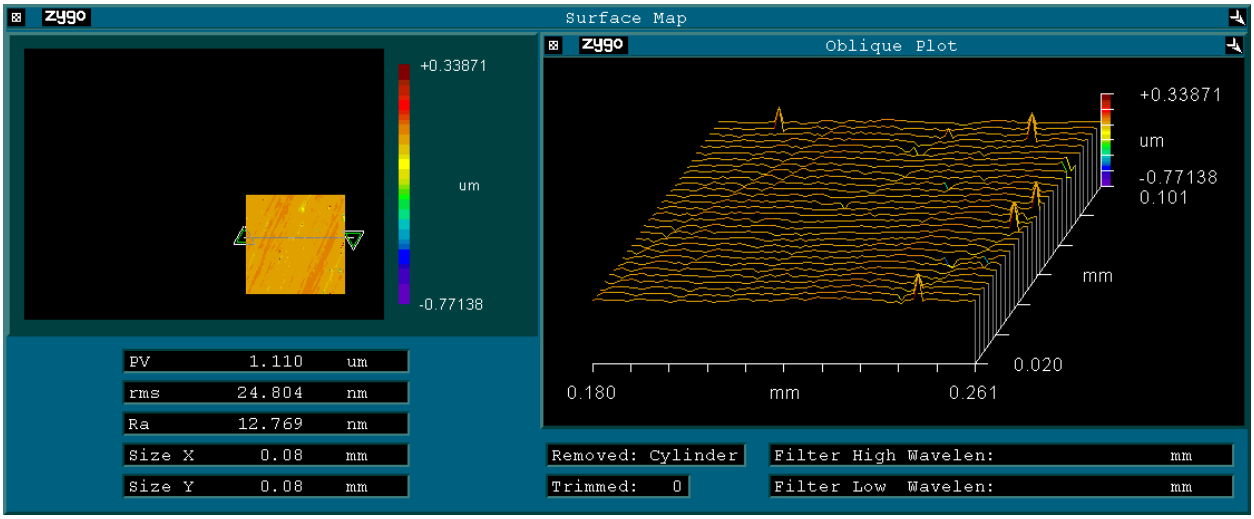

Figure 19: Surface Plot, Area 9

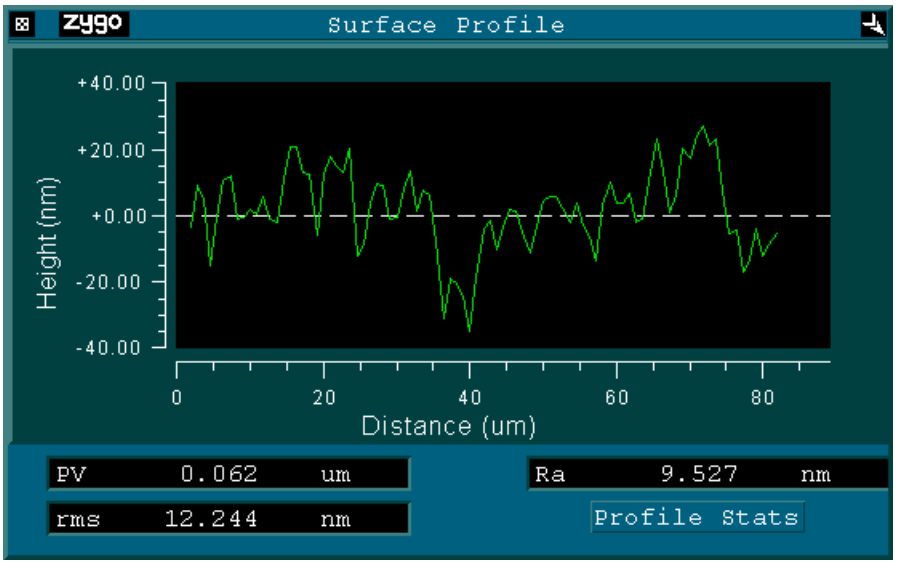

Figure 20: Surface Profile, Area 9

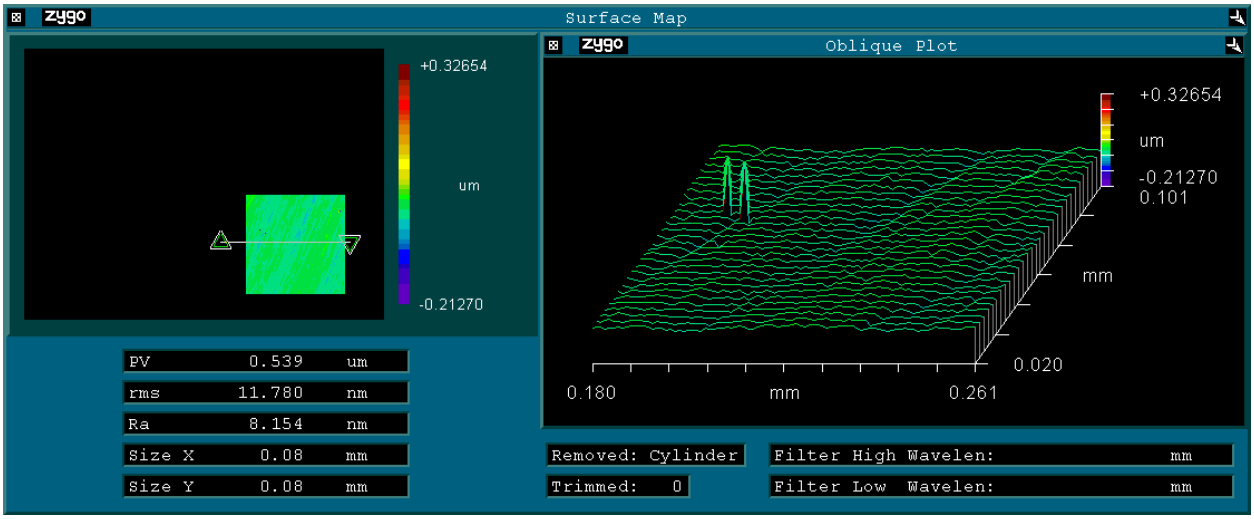

Figure 21: Surface Plot, Area 10

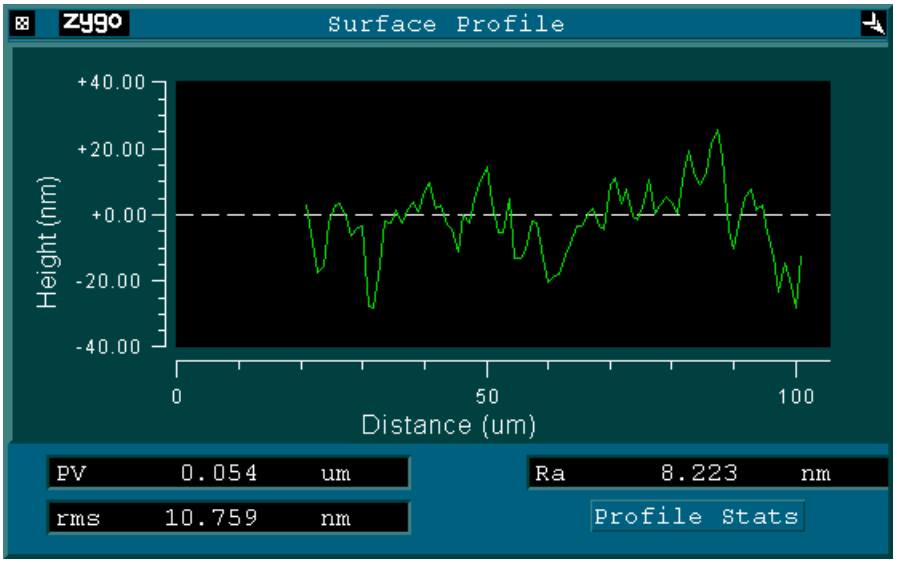

Figure 22: Surface Profile, Area 10

3. Summary

The mandrel surface finish is very good, much better than the requirements. If this finish could be maintained on the real nozzle it might run quiet to pressures substantially higher than the design condition. However, there were a few small pits on the mandrel.

It will be interesting to see if the pits caused any flaws in the electroform. It will also be interesting to see if the electroform finish duplicates the quality of the mandrel, even after heating.