SUBJECT: **Definition of a combined focal plane aperture for the SPIRE instruments**

PREPARED BY: **A G Richards**

KEYWORDS:

COMMENTS: **This document shows how a boundary is derived for an inclined planar aperture, to be located near to the telescope focal surface.**

DISTRIBUTION

B. Swinyard	(RAL)	✓
M Caldwell	(RAL)	✓
A. Richards	(RAL)	
J. Delderfield	(RAL)	✓
I. Pain	(ROE)	✓
K. Dohlen	(LAM)	✓
B. Winter	(MSSL)	✓
M. Griffin	(QMW)	✓
Project Office	(RAL)	✓

Contents

Figures and Tables

1. INTRODUCTION

The SPIRE instrument will have an aperture plate located close to the telescope focal surface. The function of this aperture is to help to control both the thermal radiation entering the main volume of the SPIRE instrument from outside and to control the view that the SPIRE instrument detectors have of the external environment. It is a requirement on this aperture that it should not restrict the view to space of either optical instrument (photometer and spectrometer) within a field of view which may be scanned over given ranges in two separate directions. Figure 1 shows schematically where this aperture is to be located.

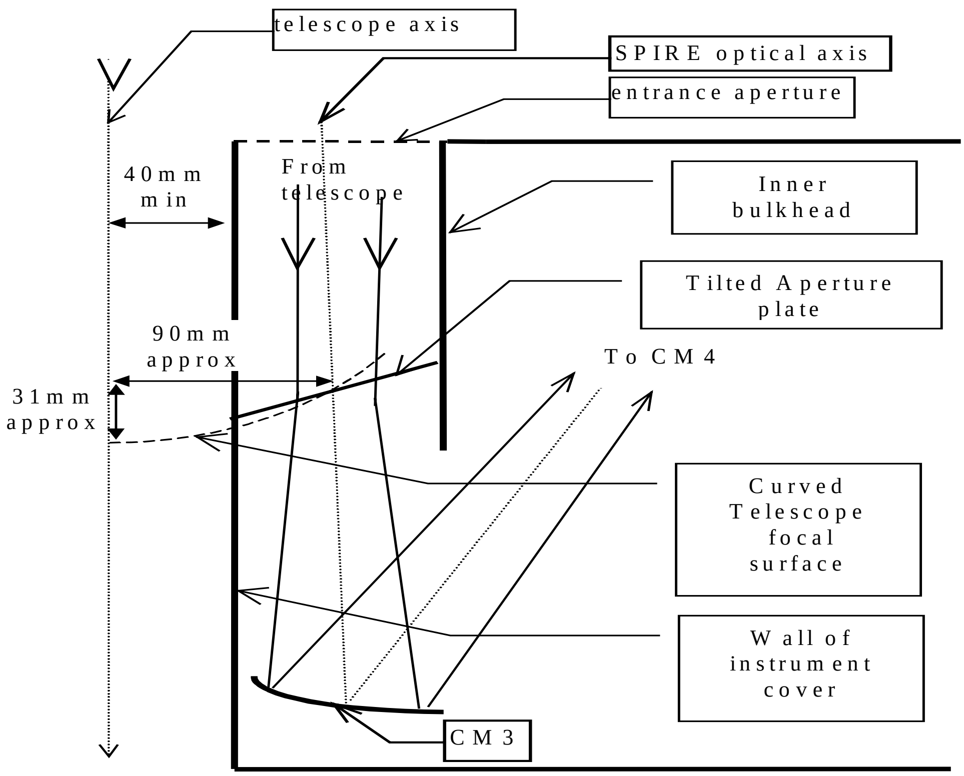

Figure 1 Schematic showing proposed location for an instrument aperture plate

In the above figure, a beam from the FIRST telescope covering a certain field of view on the sky, is shown being focussed and then travelling on to meet the SPIRE instrument's objective mirror CM3, from whence it is reflected towards a steerable mirror, CM4. The beam shown could represent the beam entering either of the two instruments making up SPIRE. In the view shown, the beams to the photometer and the spectrometer should be imagined being stacked one above the other (in the direction normal to the section shown) near the focal surface. The two instrument beams then gradually converge until they completely overlap at CM4.

The mirror CM4, being steerable to limited extents about two orthogonal axes, permits each instrument to view a region of the sky bigger than that defined by the size of each detector and the focal length of the instrument. When CM4 is said to be ‘chopped’, it is tilted through a small angle so that the field of view seen by each detector is extended in a direction into or out of the section shown in figure 1. When CM4 is ‘jiggled’, it is tilted so that the field of view is extended parallel to the plane of the section shown. The amplitudes of the ‘chop’ and ‘jiggle’ angles required for CM4 (and the resulting range of movements on the sky) are given in table 1 (N.B. the signs are arbitrary).

Tilt direction	Tilt amplitude of CM4 (degrees)		FOV movement on the sky (arc minutes)	
CHOP	+2.336	-2.336	+2.0	-2.0
JIGGLE	+0.573	-0.573	+0.5	-0.5

Table 1 Maximum tilt angles applied to CM4 and resulting FOV movements on the sky

2. REQUIREMENTS ON APERTURE SIZE AND LOCATION

2.1 Aperture size

The CM4 tilt ranges given in table 1 are requirements on the design of the drive system for CM4. The requirements on what extended field of view for each instrument the aperture plate should transmit are given in table 2.

Tilt direction	PHOTOMETER FOV extension required (arc minutes)		SPECTROMETER FOV extension required (arc minutes)	
CHOP	+2.0	-0.5	+0.5	-0.5
JIGGLE	+0.5	-0.5	+0.5	-0.5

Table 2 FOV extensions sought for each instrument

It must be noted therefore that, although the nominal field of view of both instruments will be chopped over the full amplitude, it is not required that the aperture plate permit the spectrometer field of view to be extended by the full +2 or - 2 arc minutes obtainable. It is only required to permit the spectrometer field of view to be extended by +30 and - 30 arc seconds in the chop direction. However, the aperture plate must permit the extension of both fields of view in the ‘jiggle’ direction by the full amplitude of +- 30 arc seconds. Finally table 2 shows that extension of the photometer field of view by the full 2 arc minutes is only required in one direction (that taking it towards the spectrometer field of view), extension by only 0.5 arc minutes in the opposite direction is required.

2.2 Aperture location

The location of the plane of the aperture will be determined as follows. First, it is necessary to look at the optical system of each instrument in reverse i.e. as a system for imaging a detector at the focal surface of the telescope. Then as CM4 is chopped/jiggled to its extreme values, images of points at the edges of each detector will approach the physical edges of the aperture. If these images are blurred out as a result of them not being near best focus in the plane of the aperture, then the aperture boundaries will have to be enlarged to ensure that no vignetting occurs. In order to minimise the aperture area, it is necessary to adjust the tilt and position of the aperture so that the extreme edges of the extended fields of view are in reasonable focus – remembering that it is the focus of the optical system in its REVERSE direction that is being considered here.

Figure 1 shows an aperture plane that is tilted through an angle about an axis normal to the plane of the diagram. This was the only type of tilt, in the sense shown, which was applied to the aperture plane during modelling. A second, compound tilt was not considered for reasons of simplicity.

3. THE MODELLING METHOD

CODEV models of the 'reversed' optical systems form the basis of the way the aperture boundary was determined. The term 'reversed' means that the first optical surface (the object surface) is the detector and the last 'image' surface is a surface outside the FIRST telescope, this being the reverse of the normal sequence when analysing the imaging performance of an optical system.

By tracing rays out from the detector through a reversed system, one can follow the footprints of beams that define the geometrical optical view (i.e. ignoring diffraction) that the detector has of the surfaces distributed along the optical path. This technique has been used to generate beam 'footprints' and envelopes, to guide the sizing of mirrors in and structural surfaces surrounding the SPIRE optical system. These beam envelopes are defined by bundles of rays originating from various starting points (distributed around the edge of each detector) through points distributed around the edge of a system aperture stop. In the SPIRE photometer, this stop is located between mirrors PM8 and PM9. In the spectrometer, the stop is located between mirrors SM7 and SM6.

For the present study, all that was required was to use CODEV to trace rays that define beams from a detector up to the telescope focal surface and beyond. Separate sets of rays were generated for each extreme combination of chop and jiggle tilts applied to CM4 (see table 1). The footprint of each beam was calculated at a plane representing the aperture. The angle of tilt of this plane was adjustable in each CODEV model, as was the position of a reference point on the plane (N.B. only one tilt axis for the plane was considered – along a normal to the plane of figure 1). The combined footprints in this aperture plane were then plotted by CODEV. The tilt angle of the plane was adjusted and footprint plots were repeated and examined at each tilt angle. Occasional changes were made to the co-ordinates of the reference point. Figure 2 shows a near optimum solution that was adopted as the final one. Table 3 sets out the parameters defining this 'near optimum' plane.

Parameter	Parameter Value
Tilt angle	18.0 degrees
Reference Point lateral distance from telescope axis	89.980 mm
Reference Point distance above telescope axial focus	30.943 mm
Reference Point distance from photometer fold plane	0.0 mm

Table 3 Parameters defining the aperture plane

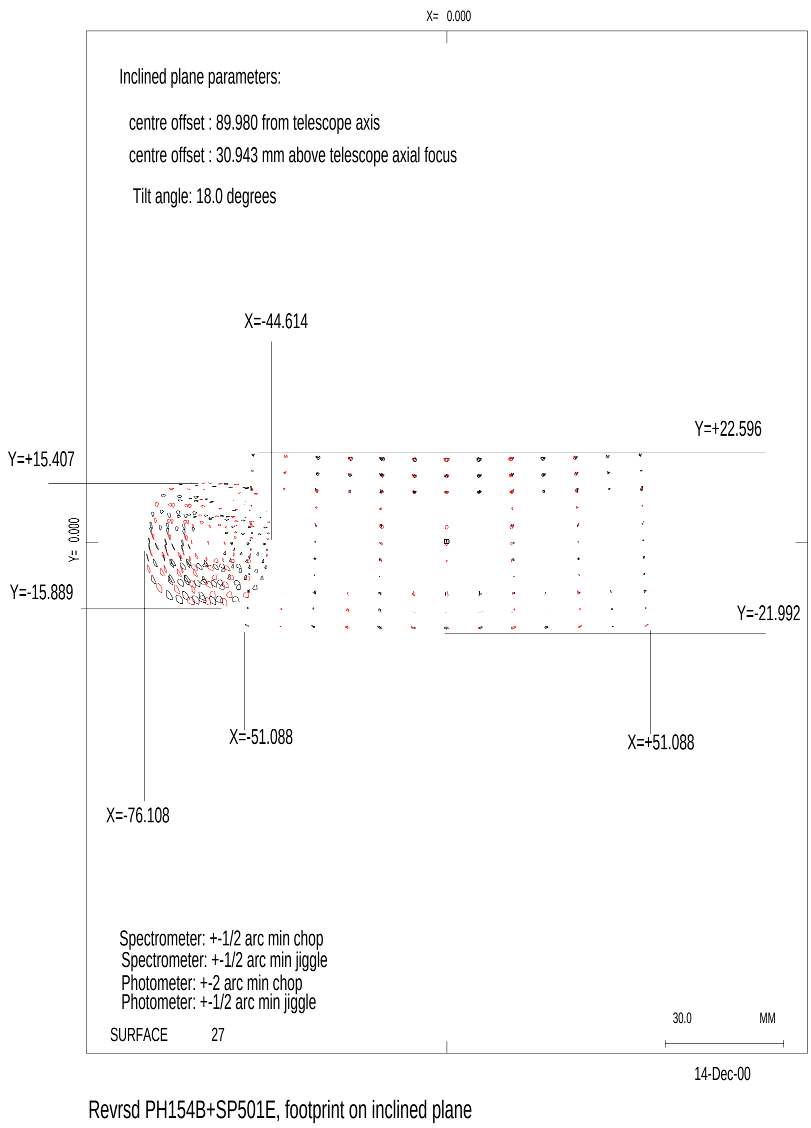

Figure 2 Extreme footprint boundaries in a near-optimum aperture plane

Note that figure 2 the X and Y directions are in the plane of the figure and internal to CODEV.

4. DEFINING THE APERTURE BOUNDARY

4.1 Minimum size boundary

Table 4 summarises the extreme boundaries of the combined footprints shown in figure 2. The total widths between the boundaries are given, as are the theoretical locations of the centres of rectangles having these extreme dimensions. They represent the minimum dimensions of the simplest type of parallel-sided aperture that will fit around the footprints of each instrument.

	Boundaries				Widths		Centres	
Footprint	-X	+X	-Y	+Y	X width	Y width	X centre	Y centre
Photometer	-51.088	51.088	-21.992	22.596	102.176	44.588	0.0	0.302
Spectrometer	-76.108	-44.614	-15.889	15.407	31.494	31.296	-60.361	-0.241

Table 4 Footprint dimensions obtained using CM4 tilt angles from table 1

The determination of that part of the aperture boundary defined by the photometer footprints uses the fact that only -0.5 arc minutes extension is required in one chop direction, as is specified in table 2. Note that this chop movement takes the photometer field of view AWAY from the spectrometer field of view. Figure 2 shows the result of 2 arc minutes extension in this direction, which gives an approximate 6 arc minute half-width for the full photometer field of view footprint in the aperture plane. Therefore in order to get the equivalent to a 0.5 arc minute extension to the 4 arc minute half-width of the photometer field of view, the half-width must be scaled by a factor 4.5/6. The result is that the +X edge of the photometer footprint boundary should be put at 51.088*4.5/6=+38.316 mm. This will give a reduced total width and a different centre for the rectangle that covers the footprint. These revised photometer footprint values are given in table 5.

	Boundaries				Widths		Centres	
Footprint	-X	+X	-Y	+Y	X width	Y width	X centre	Y centre
Photometer	-51.088	38.316	-21.992	22.596	89.404	44.588	-6.386	0.302

Table 5 Revised Photometer footprint dimensions corresponding to CM4 tilt angles from table 2

4.2 Boundary Clearance

Some clearance value must be added to the values for the photometer and spectrometer boundary values given in tables 4 and 5 respectively. This is to allow for manufacturing error and mechanical and optical misalignments. However, no clear method presently exists for determining an optimum, minimum clearance for this component that will ensure that the aperture edge remains clear of the chopped and jiggled fields of view, when they have been extended by the maximum amounts specified in table 2. To proceed with a design, a minimum clearance of 1 mm all round has been adopted. This value can be modified later if necessary. A 1 mm clearance added to the extreme X and Y values in tables 4 and 5 yields the final specification shown in table 6, where two new parameters, the radii to be used at the corners of the bounding rectangles, have been added. The resulting boundaries are shown superimposed on the footprints in figure 3.

	Boundaries				Widths		Centres	
Footprint	-X	+X	-Y	+Y	X width	Y width	X centre	Y centre
Photometer	-52.088	39.316	-22.992	23.596	91.404	46.588	-6.386	0.302
Spectrometer	-77.108	-45.614	-16.889	16.407	33.494	33.296	-60.361	-0.241
	Corner radius							
Photometer	2.0							
Spectrometer	10.0							

Table 6 Dimensions and locations of the rectangular components of the aperture boundary

Note that the clearance at the vast majority of points around the perimeter of the combined field of view footprints will exceed 1 mm because of the shape of the footprints compared to the rectangular shape proposed for the aperture. The points where the minimum clearance exists are located near the ends of the lines that are drawn in figure 2 to indicate the extreme X and Y limits of each instrument’s footprint.

The X and Y data in table 6 data are referred to co-ordinate axes in a tilted plane whose origin is specified in table 3.

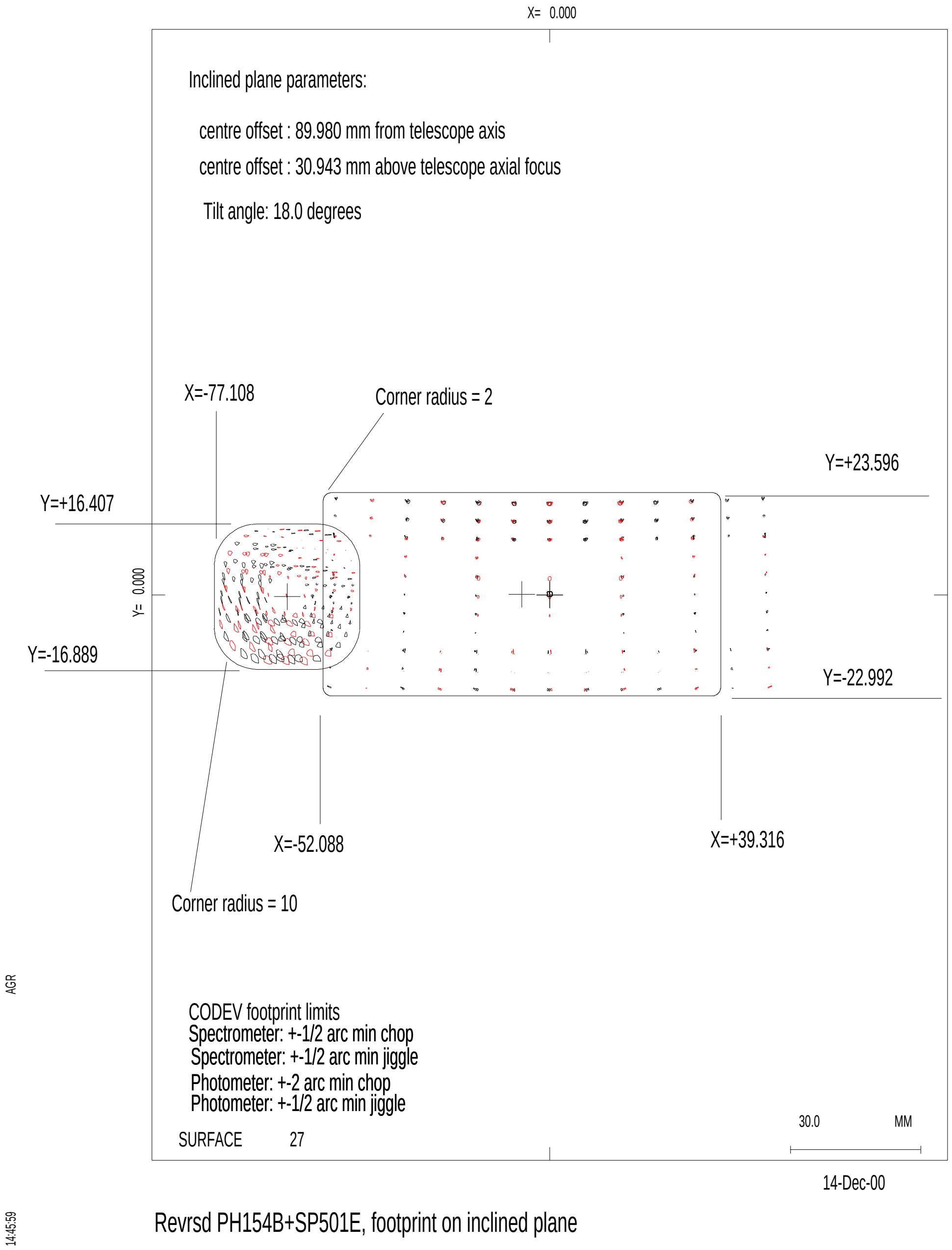

Figure 3 Clearance aperture boundaries superimposed on extreme footprints

4.3 Composite aperture boundary details

The actual aperture boundary needs to be a composite of the two round-cornered rectangles shown in figure 3. Where the two rectangles intersect, a rounded internal corner, radius Rint = 4 mm, is introduced. All of the dimensions needed to define the boundary are set out in figure 4 and table 7.

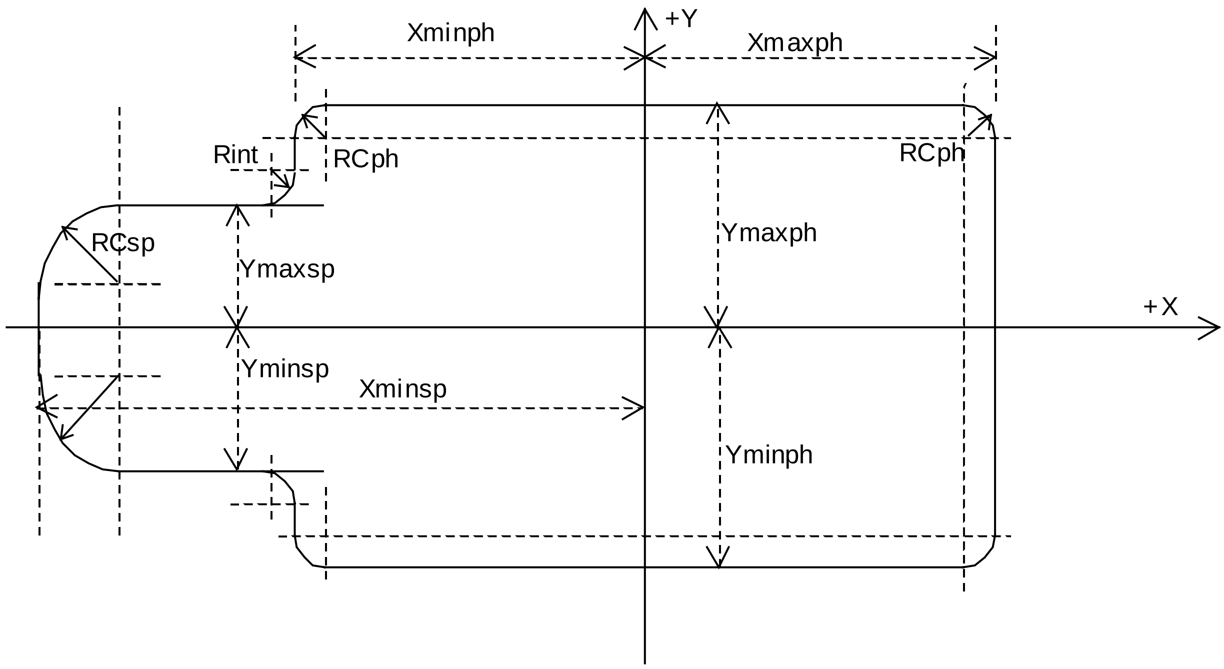

Figure 4 Dimensions determining the composite aperture boundary

Dimension Label in figure 4	Value (mm)
Xmaxph	39.316
Xminph	-52.088
Ymaxph	23.596
Yminph	-22.992
RCph	2.0
Rint	4.0
Xminsp	-77.108
Ymaxsp	16.407
Yminsp	-16.889
RCsp	10.0

Table 7 Values for the dimensions that determine the composite aperture boundary

The X-Y co-ordinates in figure 4 are in the plane of the tilted aperture. The origin of the co-ordinates is the reference point whose co-ordinates are given in table 3, as is the tilt angle.

5. GENERATING A 3-D MODEL OF THE APERTURE

A 3-D model of the aperture, in the form of an IGES-format file, was generated so that it could be incorporated into the CAD model of SPIRE. This was achieved by expressing the aperture boundary as four linked cubic spline curves and by imposing a rectangular outer boundary, also described by four cubic spline curves linked at the four corners. This allowed the surface between the inner aperture boundary and the outer bounding rectangle to be represented as four 'ruled surfaces', each defined and generated by a pair of spline curves, one drawn from each set of four boundary curves.

In order to provide a 3-dimensional aperture, a thickness APTHICK was specified for an aperture plate (1.0 mm was the initial choice – this can be changed in future, if necessary) and a second aperture surface was created in a plane located at this thickness above the first aperture plane. The inner boundary of the aperture in this second plane was generated assuming a 45-degree bevel at the edge of the inner boundary first aperture. Because tan(45)=1, this results in an aperture boundary which is a uniform distance APTHICK all round the outside of the first aperture but in a plane displaced ATHICK normal to the aperture plane. The points defining this second aperture boundary were generated from the points on the spline curves making up the first boundary by projecting them a distance √2*ATHICK at 45 degrees inclination and in the appropriate azimuthal direction[1]. The spline curves making up the rectangular outer boundary in this second aperture plane were generated from the spline curves making up the rectangular boundary of the first aperture by just incrementing the co-ordinate normal to the plane of the aperture by ATHICK.

The surface making up the second aperture surface was generated using four ruled surfaces in the same way as the first aperture plane. The surface of the bevel was generated using four ruled surfaces, this time each ruled surface was generated using a pair of spline curves with one drawn from each of the two groups of 4 splines generating the inner boundaries of both apertures. The surfaces making up the four edges of the rectangular aperture plate were generated using corresponding pairs of edge splines.

The computation of the spline data was carried out in a MATHCAD file, which also generated data defining the points of a wireframe model. Figure 5 shows the points defining the two inner boundary curves, taken from the MATHCAD file. Figure 6 shows the wireframe model that was generated and figure 7 shows the 3-D model generated from the IGES file that was created using the SPLINEIGS application.

The applications used and data files generated are listed in table 8.

[1] The azimuthal direction at a point on the boundary was always chosen to be at 90 degrees to the tangent to the boundary curve at that point.

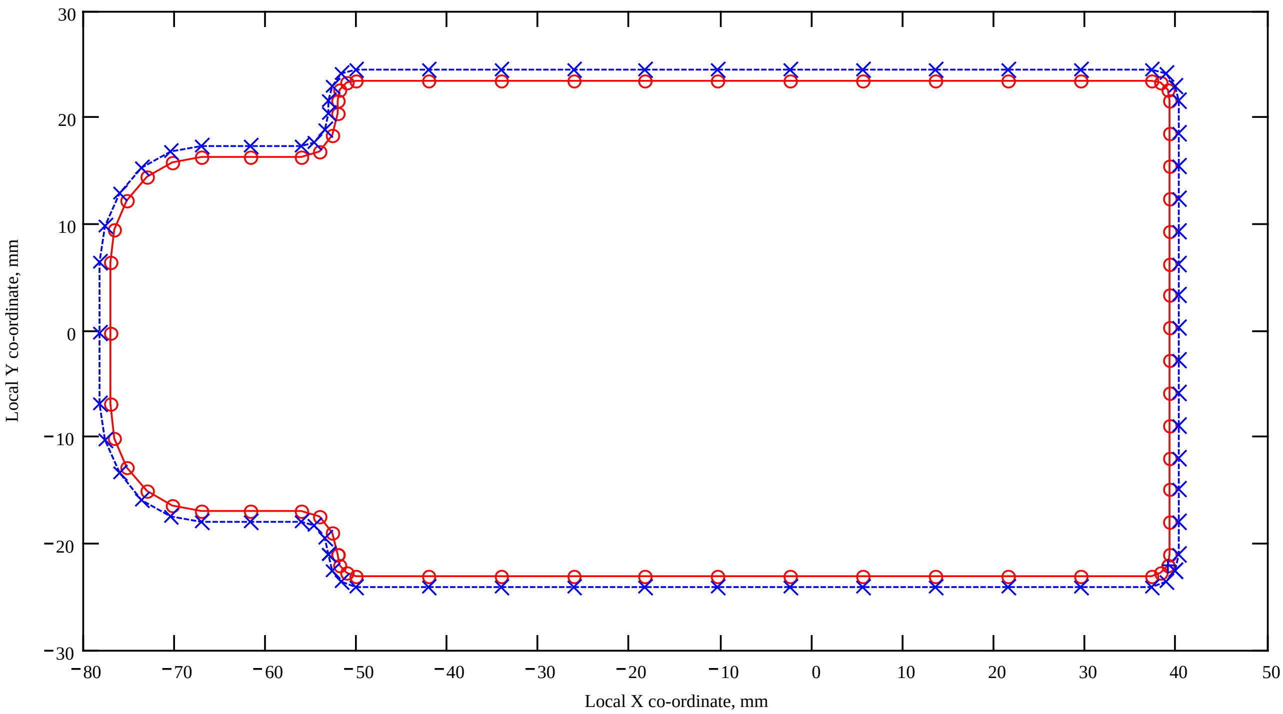

Figure 5 Aperture boundaries, showing the points on the cubic spline curves used to fit them

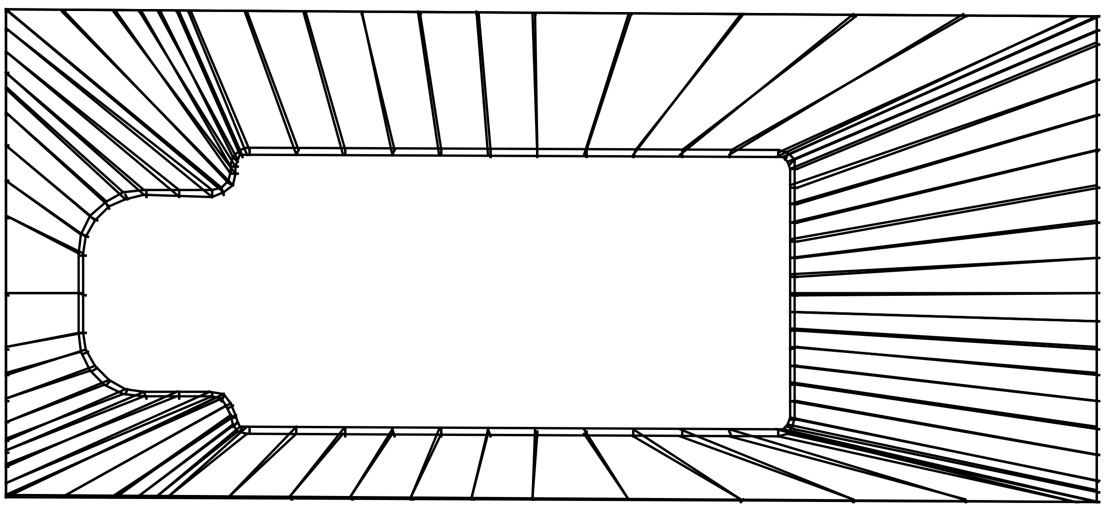

Figure 6 Wire-frame model of aperture plate

The wire-frame model illustrates how corresponding points on pairs of spline curves are joined when generating the 2-dimensional ruled surfaces which make up one of the aperture plate surfaces.

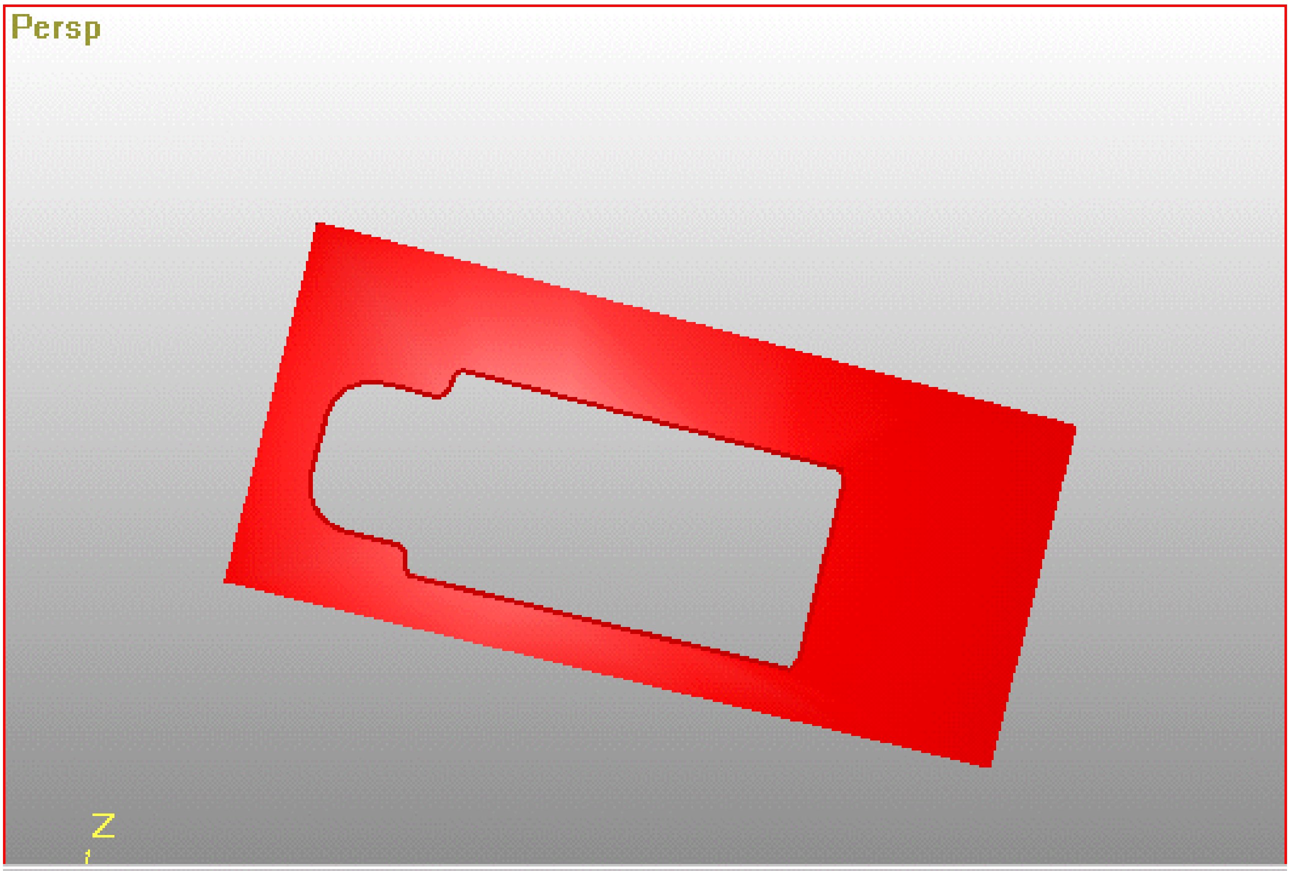

Figure 7 3-D view of the aperture plate obtained by importing its IGES file

Application / file	Inputs	Outputs
M4M3FP_BEAMS_OS.MCD (MATHCAD document)	CODEV aperture boundary data Aperture plate tilt Aperture reference point Aperture plate thickness	FPBAFFAP.WIR FPBAFFAP.BOU
SPLINEIGS.EXE	FPBAFFAP.BOU (spline curve data)	FPBAFFAP.IGS
WIREFRAME.EXE	FPBAFFAP.WIR	Wire-frame display
3DVIEW.EXE	FPBAFFAP.IGS	3-D view

Table 8 Applications and files used to create a 3-D model of the aperture plate