	ATLAS SCT END-CAP Module FDR				
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SCT END-CAP MODULE Document

SCT End-cap Module Components: Spines

Abstract

This document describes the requirements and details of the thermo-mechanical spine that forms part of the SCT end-cap module. The assembly processes are explained and reviews are given of the components and product specifications. The methods of achieving both component assurance and spine quality assurance are described, and finally the production schedule is presented.

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1. SCOPE OF THE DOCUMENT

This document :

- describes the end-cap module spines and their fundamental requirements,
- considers the role of the spine within the construction and performance of a module
- gives the technical specifications of their components
- explains their assembly procedures,
- discusses the details of quality assurance procedures
- reviews the preparations for pre-series and subsequent series production
- and summarises the future production plans.

2. THE END-CAP MODULE SPINE

The spine is the central element of the end-cap module, sandwiched between silicon wafers on each of its sides during the module construction. To minimise the overall material within a module the spine must have the lowest possible mass, be mechanically rigid, and provide the interface for the module cooling contacts. Intrinsically the spine must be highly efficient in its thermal transfer capabilities in order to transmit injected heat from both the attached ASIC-hybrid structure and, after some years of running, the leakage currents of the silicon detectors that will arise from radiation damage. The ability to achieve the latter requirement is known as the safety against thermal runaway, as such leakage currents double with every 7°C increase in silicon temperature and hence are a potential source of uncontrolled temperature rise. The results of detailed finite element calculations are shown in the documents ATL-IS-EN-0007, and are compared with experimental data in ATL-IS-TR-0002. The low mass has been achieved by designing a minimal volume spine, constructed from customised graphite sheets of very high thermal conductivity.

An exploded view of a module with the spine as central part spine is given in Figure 1: It is made of a central heat spreader conducting the heat produced in the silicon detectors to the cooling contacts at both ends of the module. Ceramic wings attached to the central part support the silicon detectors and are also used to distribute the bias voltage to the detectors.

The heat spreader substrate is Thermal Pyrolytic Graphite (TPG). The TPG is an anisotropic material having both mechanical and thermal properties that, due to the planar mosaic ordering of the carbon structures, are basically constant within the plane of a substrate sheet and are significantly different in the orthogonal direction. The main features of the 500 ± 25µm thick sheets of TPG are: (a) in-plane thermal conductivity typically in the range 1500-1700 W/mK at temperatures around 20°C, and increasing by 0.4% for each degree lower in temperature, and (b) a transverse thermal conductivity of typically 8 W/mK. The TPG was developed and characterized in an INTAS supported project (CERN/INTAS 99-249).

In order to achieve electrical insulation and mechanical protection the TPG is coated with a 10µm layer of Parylene-C.

Since TPG is fragile and tends to delaminate the structure of the spine has to be reinforced using aluminium nitride (AlN) ceramic materials.

AlN has a rather high thermal conductivity of 180 W/mK at 20°C. The plates covering the TPG at the cooling contacts are 225 ± 25 µm thick. They are needed to ensure good thermal contact to the cooling points while protecting the soft TPG from mechanical damage. The

wings supporting the detectors and providing mechanical stiffness to the detector spine assembly have a thickness of 500 ± 25 µm. Some of the AlN pieces contain metal traces to supply the bias contact of the detectors.
The detailed spine design has been the result of a long optimisation process taking into account thermal and mechanical performance as well as cost and ease of assembly.

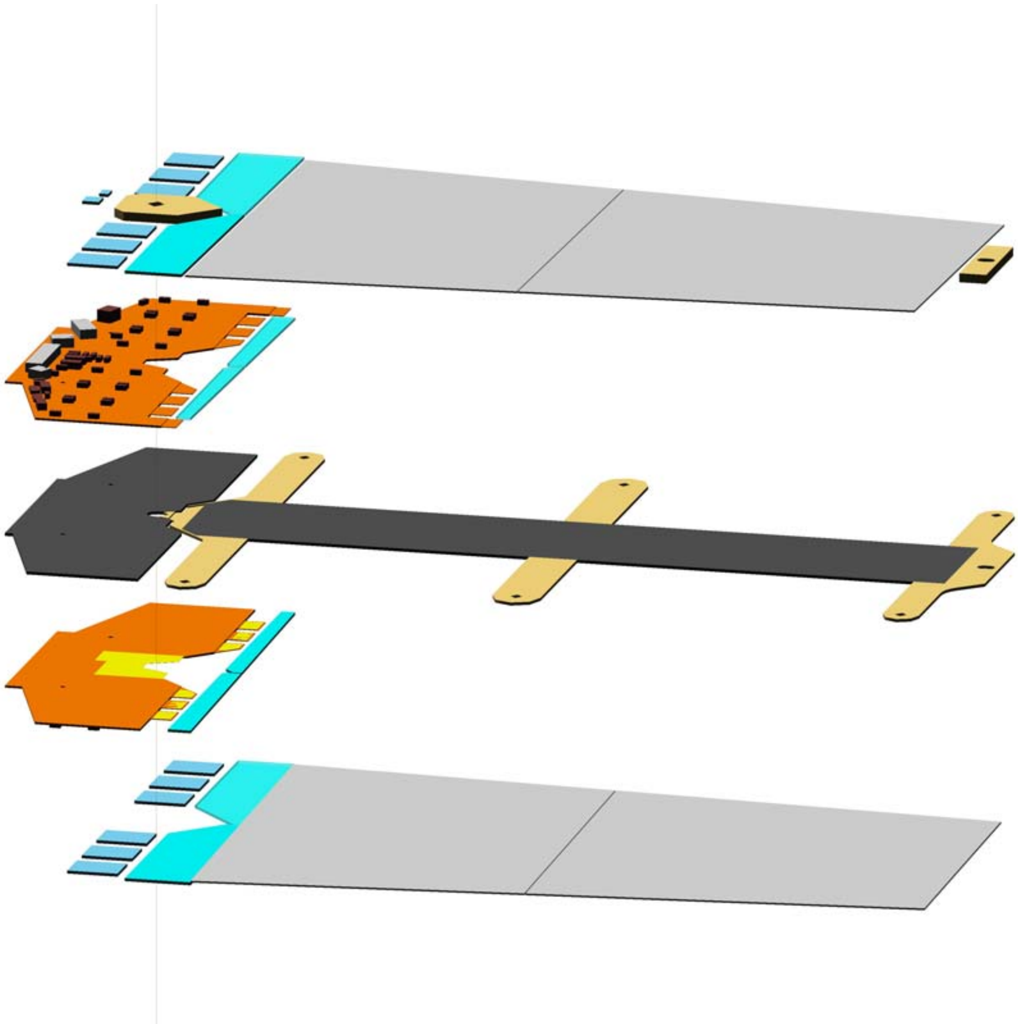

Figure 1: Exploded view of module components with spine as central mechanical structure, sandwiched between the silicon detectors.

A picture of an assembled pre-series spine is shown in Figure 2. Geometrical specifications of the spine and its components are given in the Appendix.

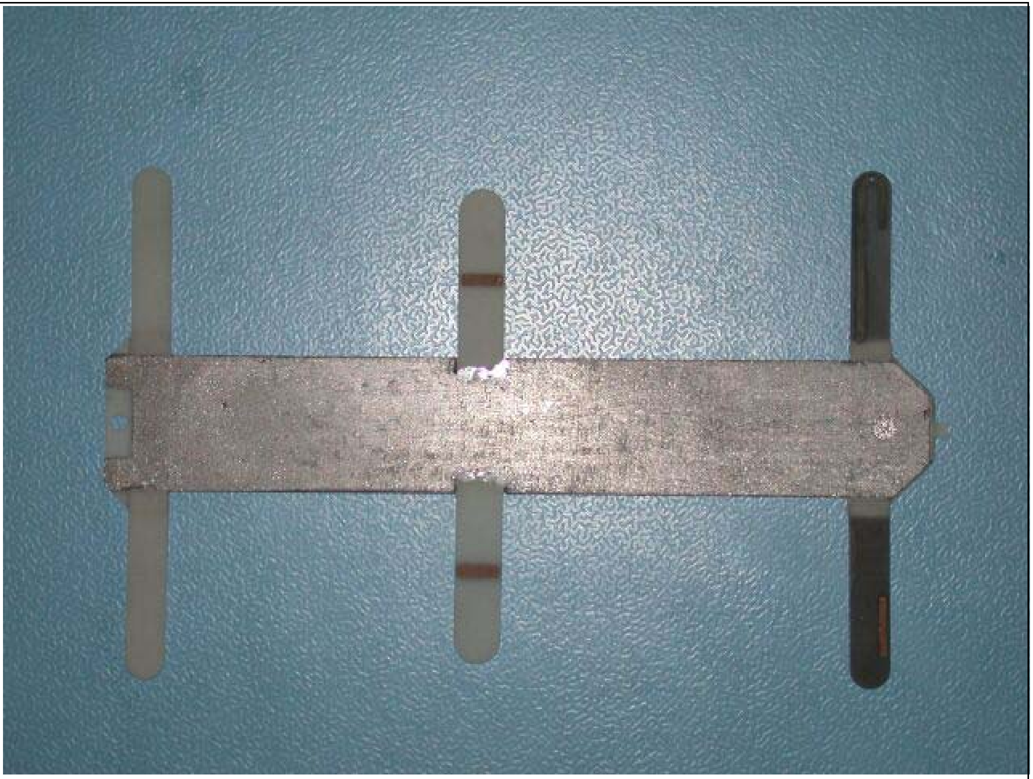

Figure 2. TPG spine with AlN wings

3. COMPONENT SPECIFICATIONS AND ASSURANCE

3.1 The AlN ceramics

AlN has been chosen because of its high thermal conductivity and its thermal expansion coefficient which is well matched to Silicon, thus reducing stress during temperature changes of the module. The spacers are made from Al_2O_3, mainly because of its low thermal conductivity, thus acting as a heat barrier between hybrid and silicon detectors. The properties of the materials are given in Table 1.

	AlN	Al_2O_3
thermal conductivity:	180 W/mK	20 W/mK
density:	3.3 g/cm³	3.75 g/cm³
electrical conductivity:	>10^4 Ohm cm	
thermal expansion coefficient	3.1 10^{-6} (at 20°C) [6]	6.7 10^{-6} (at 20°C)

Table 1: Properties of the ceramic material used for the spines. Data are from CERAMTEC [5], unless noted otherwise.

3.2 The TPG Substrates

The thermal and mechanical properties of sample substrates have been extensively studied over the last three years [1,2,3], with the necessary dedicated equipment having been designed and built specially for this project. The thermal conductivity has been measured both in-plane and transverse to verify the material properties.

The properties of the TPG are:

- in-plane thermal conductivity: 1550 ± 130 W/mK (at 20°C)
- out of plane thermal conductivity: 8.9 ± 0.4 W/mK (at 20°C)
- density: 2.15 ± 0.2 g/cm³
- transverse pull strength: 56.5 ± 14.2 N/cm²
- in-plane electrical conductivity: 1.63 x 10^6 [Ohm m]$^{-1}$
- thermal expansion coefficient (in-plane): (-1.17 ± 0.15) 10^{-6}/°C (at 20°C)
- thermal expansion coefficient (out of plane): (26.8 ± 0.4) 10^{-6}/°C (at 20°C)

3.3 Glue

The gluing of the TPG to the thin ALN sheets at the cooling block connections needs glue with high thermal conductivity. After a series of tests [4] ELASTOSIL 137-182 (available in Russia) was chosen. The thermal conductivity has been measured to be C_k = 1.79 ± 0.1 W/mK. As comparison ARALDITE 2011 with 25% boron nitride filler has conductivity of C_k = 0.87 ± 0.06 W/mK. Tests of the force needed for disruption demonstrated a glue strength superior to ARALDITE. No deterioration of the glue strength after irradiations up to 2.7 x 10^{15} p/cm² was observed.

4. THE PRODUCTION PROCESS AND QUALITY ASSURANCE

The TPG is be produced and roughly cut by NIIGraphite [7]. This will result in plates of 150 x 25 x 0.7 mm³. These plates are polished into the exact shape at NIITAP [8] and coated with a 10 µm layer of Parylene-C. Parylene-C was chosen because it has less tendency to penetrate into the TPG layers during deposition. Such an effect was observed with Parylene-N and leads to an increase of the TPG thickness at the cutting edges. Before coating the TPG is heated to 200°C for 30 min and kept 45 min under vacuum to avoid later outgasing.

The contact hole for the bias contact is made using plasma etching. This hole allows to contact the TPG and bias it to the same voltage as the detector backside.

The AlN ceramic parts are laser cut and profiled at NIITAP. Conductive Al layers, which build up during cutting, will be removed using NaOH. Afterwards the pieces are cleaned with distilled water.

The metal traces are made using vacuum evaporation of Ti-Cu-Ni.. The total thickness of the three layers is 2 µm. The electrical resistivity must be lower than 20 Ohm between any two points of a trace.

The through contact between bias line and backside metallization of the contact hole is made using Ti-Cu-Ni

The Al_2O_3 spacers are be cut and metallized at NIITAP using the same techniques.

Final assembly of the components is done at IHEP. The AlN facings are glued to the TPG using ELASTOSIL [4] thermal conductive glue.

After assembly the spines are inspected and the thickness is measured at 25 pre-defined points. The flatness will be measured and spines which are bowed too much will be rejected. The criteria needs to be defined taking into account the

- impact on the flatness of the final module,
- proper dispensing of glue.

Each completed spine is subject to a quality assurance of its thermal performance and electrical contact-continuity. The electrical continuity is checked by direct measurements between the contact pads on the AlN facings and the HV openings on the TPG area. Thermal measurements are provided by periodically injecting heat at the main cooling contact and measuring the phase shift of the periodic temperature variation at the second cooling point. Data for each board are recorded, and stored in a database.

Each spine is given a bar-coded identity from the SCT database and is finally inspected visually before packaging. The plastic package is labelled to identify the spine.

About 100 spines have been produced so far, ca. 40 of them close to the final design described here. The final tooling exists.

6. THE PRODUCTION SCHEDULE

The nominal number of spines needed is 1976. Assuming a contingency of 25% a total of 2470 spines has to be produced. A breakdown for the different module types is given in Table 2.

Type	**Nominal**	**Incl. Contingency**
Outer	936	1170
Middle	640	801
Inner	400	499
Total	**1976**	**2470**

Table 2: Number of spines to be produced

The fabrication facility is now commissioned at IHEP and can be brought into full production during the next months.

- Pre-series fabrication of 450 spines has begun in May 2002 and can be finished in September. This pre-production is needed for pre-series modules and site qualifications.
- The series of 2020 spines will begin after the PRR and can be completed in 21 months. The limiting factor is the machining of the AlN and TPG parts. The raw TPG can be made in 18 months. IHEP could assemble up to 320 spines per month. A tentative production schedule is shown in Table 3.

Date	**Outer**	**Middle**	**Inner**
Pre-Series	150	150	150

1. quarter year	82	59	47
2. quarter year	95	87	75
3. quarter year	125	101	90
4. quarter year	125	101	90
5. quarter year	168	101	47
6. quarter year	215	101	
7. quarter year	210	101	
Total	**1170**	**801**	**499**

Table 3: Production Schedule

7. REFERENCES

[1] C.A. Heusch, H.-G. Moser, A. Kholodenko, Direct measurements of the thermal conductivity of various pyrolytic graphite samples. Nucl. Inst. & Methods A480/2-3 (2002) 463-469

[2] A. Kholodenko et al., Comparison of the in-plane thermal and electrical conductivities and transverse pull strengths of various pyrolytic graphite materials, IHEP 2001-48, ATL-INDET-2002-003

[3] A. Kholodenko, H.-G. Moser, Comparison of the Thermal and Mechanical Properties of TPG used for SCT ATLAS Modules, ATL-COM-INDET-2000-006 .

[4] A. Kholodenko, H.-G. Moser, V. Riadovikov, The Thermal and Mechanical Properties of Glues for the ATLAS SCT Module Assembly, ATL-INDET-2000-007

[5] CeramTec AG, Lorenzreuther Str. 2, D-95615 Marktredwitz

[6] ITKS, Fraunhofer Institut Keramische Technologien und Sinterwerkstoffe, Wittenbergstr. 28, D-01277 Dresden.

[7] Scientific Research Institute of Carbon Based Materials, NIIGraphite. Electrodnaya Street 2, 111524 Moscow, Russia.

[8] Scientific Research Institute of Technology and Automation for Industry, NIITAP, 1st May Street, 103681 Zelenograd, Russia

APPENDIX

The geometrical specifications of the spine and its assembly are shown in Figure 3 for the outer module. Figure 4 shows the dimensions of the individual components. Figure 5 shows the spacer which is used to balance the thickness difference of the spine with respect to the hybrid. A complete set of drawings for all 3 module types can be found at `http://jupiter.ph.liv.ac.uk/~peter/atlas/atlas.html`

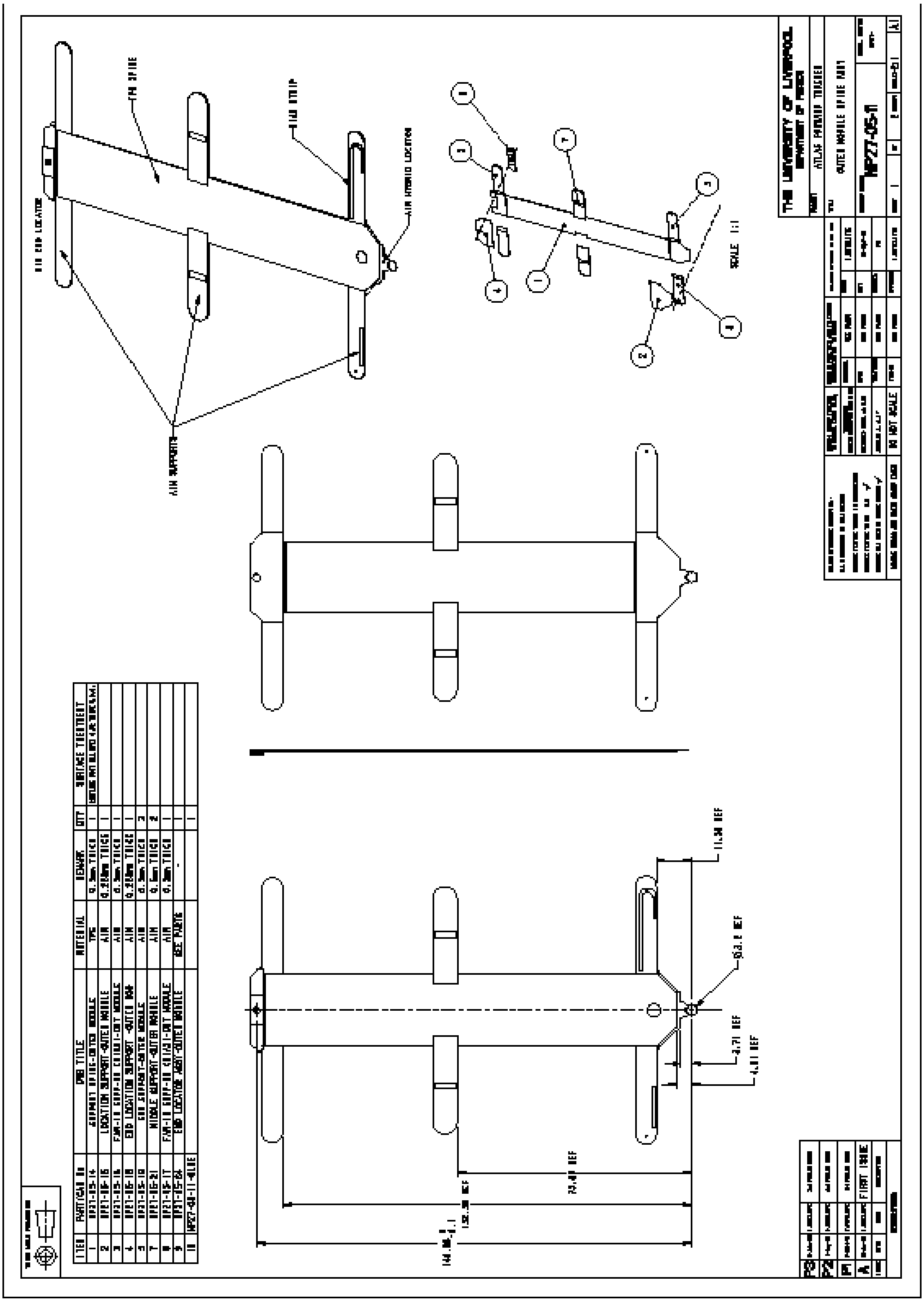

Figure 3: Geometrical dimensions and assembly of an outer module spine.

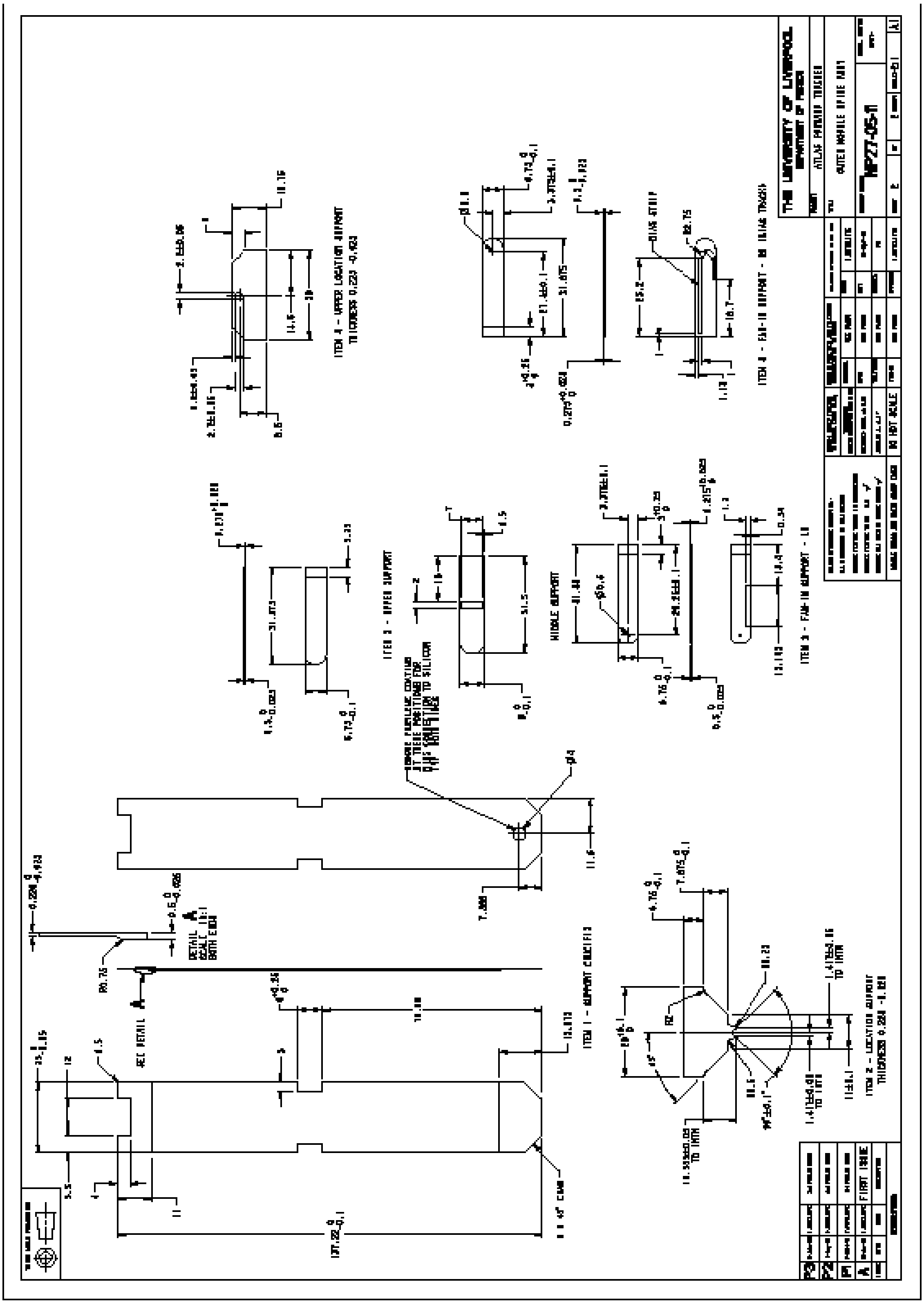

Figure 4: Geometrical dimensions of the spine components (Outer Module).

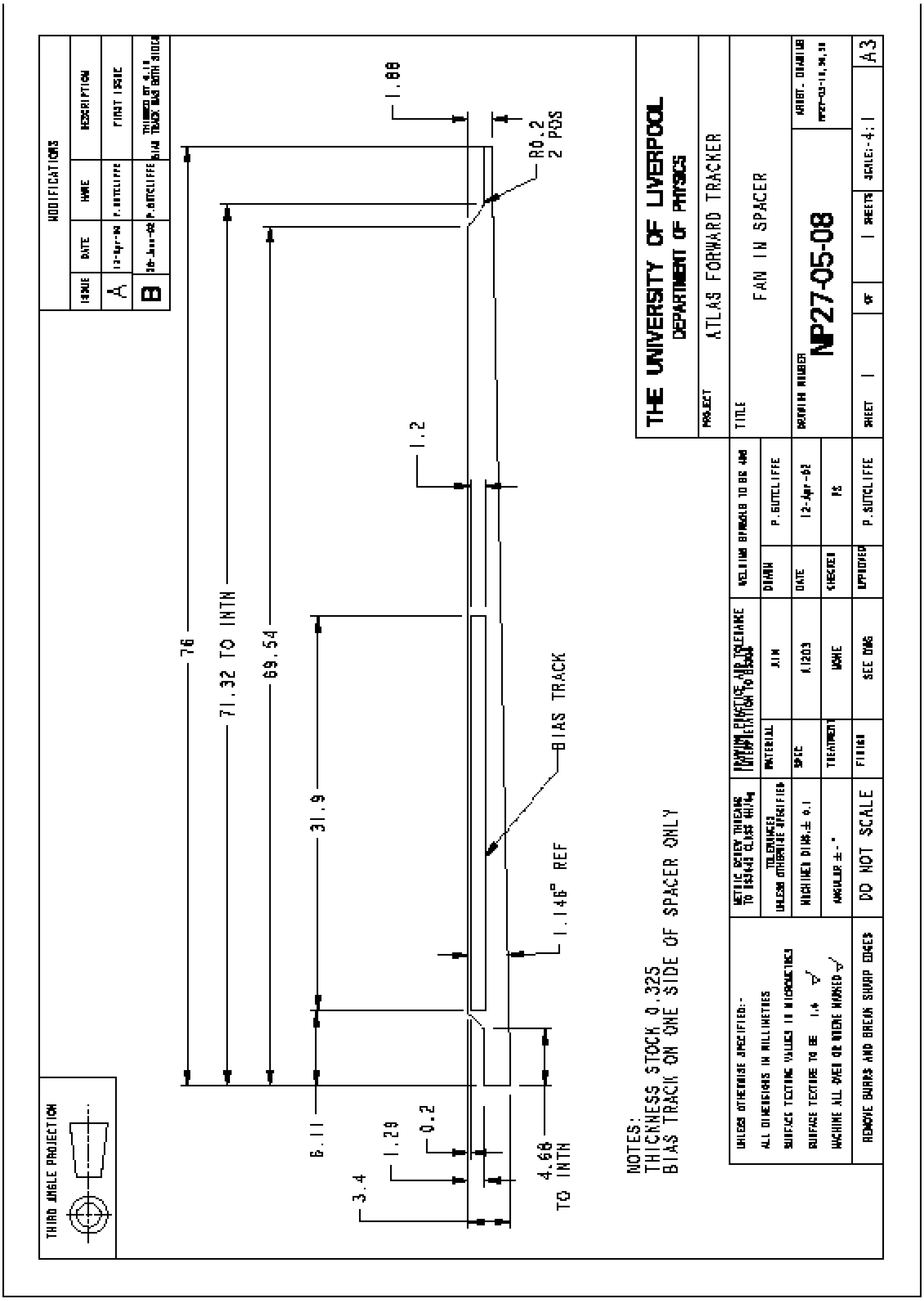

Figure 4: Spacer