



**Request for Quotation for:
Off-Axis Parabolic (OAP) Mirrors
Flat Mirrors
Spherical Mirrors**

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1. Scope

This document defines the specifications and requirements for the procurement of custom mirrors used in a coronagraph intended for exoplanet characterization.

2. Introduction

The University of Arizona (UA) Center for Astronomical Adaptive Optics (CAAO) requests a quotation for the grinding, polishing, coating, and testing of custom OAP, flat, & spherical mirrors and spare units. The optics are part of a space-based, high-contrast coronagraph. All optics and coatings shall be vacuum compatible.

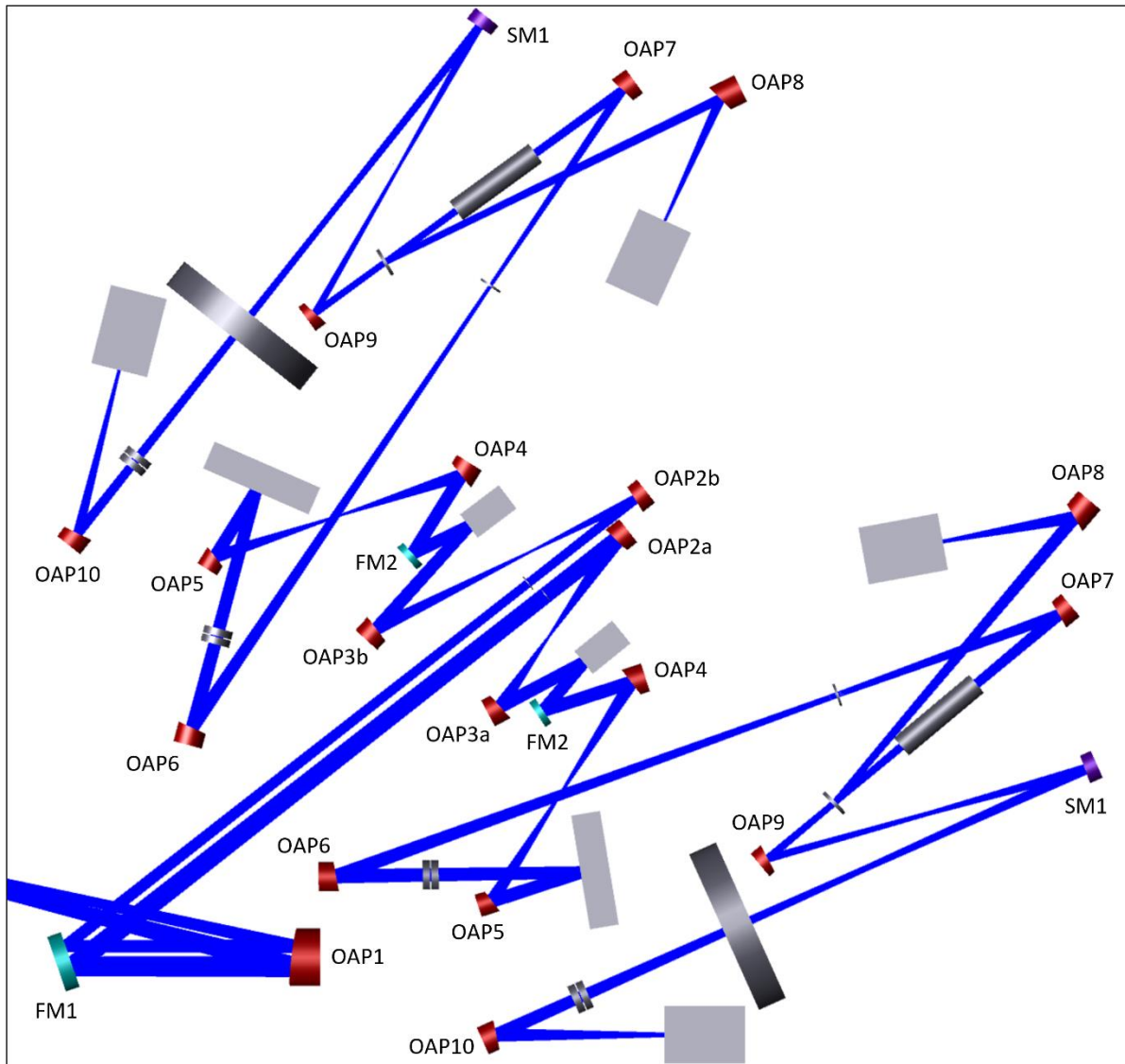


Figure 1: Illustration of optical design (OAP mirrors in red, flat mirrors in teal, spherical mirrors in purple)

The optical design uses OAP mirrors, shown in red, individually and as pairs to relay both the image plane and exit pupil of a telescope. Flat mirrors are used for packaging and are shown in teal. In addition, a pair of spherical mirrors are shown in purple. All mirrors shall operate

at room temperature and at vacuum pressure. The optical specifications are listed in Tables 2-4. All mirrors shall require a protected aluminum coating (AlMgF₂) suitable for the environmental conditions listed in Table 6. The program requires the procurement of two (2) sets of ten (10) custom OAP mirrors, two (2) sets of two (2) flat mirrors, and two (2) sets of one (1) custom spherical mirror. However, this RFQ requests pricing for quantity 3: two (2) operational sets and one (1) spare set. Exceptions to the quantity are OAP1, FM1, OAP2A & 2B, and OAP 3A & 3B which need quantity two (2) each. OAP2 has the same ROC but different OADs (OAP 2A & 2B). OAP3 has different ROCs and OADs (OAP 3A & 3B). OAP5 and OAP8 are identical to OAP4. OAP9 and OAP10 are identical. Note, OAP2, 4, 5, & 8 all have the same ROC and could be cored from the same parent parabola as a cost savings.

3. Deliverables

This RFQ shall include the following items:

Line Item	Quantity	Description
01	3*	Set of ten (10) OAP mirrors, set of one (1) spherical mirror, set of two (2) flat mirrors
02	1	OAP mirror certificate(s) of conformity
03	1	Spherical mirror certificate(s) of conformity
04	1	Flat mirror certificate(s) of conformity
05	1	Protective aluminum coating documentation
06	1	Quality control / metrology / testing report(s)
07	1	Box(es) for storage and transport

* See Tables 2-4 for exact specifications and quantities for each optic.

Table 1: RFQ deliverables

4. Off-Axis Parabolic (OAP) Mirror Descriptions & Specifications

Off-axis parabolic mirrors are used in the optical design to relay a telescope focal plane and exit pupil plane to downstream optics and sensors. All mirror substrates shall be either ULE, Zerodur, or ClearCeram-Z. However, the same substrate shall be used for all mirrors. All clear apertures (CA) shall be >85% of the outer diameter as individually specified in Tables 2-4. The center thickness (CT) for each OAP mirror is based on a nominal aspect ratio with respect to the diameter of 2:1, except OAPs 2A & 5. Flat mirrors use an aspect ratio of 4:1. The CT tolerance is relatively loose as piston adjustment is designed in the optics mount. All OAP radius of curvature tolerances shall be ±0.1%. RMS wavefront error shall be defined as 2nm or less with a goal of 0.5nm. Mid-spatial frequency errors are specified using a power spectral density ABC model (Harvey et al 2009 and references therein).

The form factor for all OAP mirrors shall be wedged with the back plano surface orthogonal to the vertex axis of the parent parabola. The back surfaces shall have an inspection-level polish. The edge surfaces shall have a ground finish. The vendor shall mark the edge of each OAP and spherical mirror with two (2) etched scribe lines indicating the direction of the parent vertex axis (thin edge) and opposite edge (thick edge). A pencil or marker scribe line

is not acceptable. Note that OAP 2A requires a truncated diameter. The truncated area shall be removed from the thick edge of the mirror. The substrate shall be truncated 2.7mm in radial depth prior to grinding and polishing as shown in Figure 4.

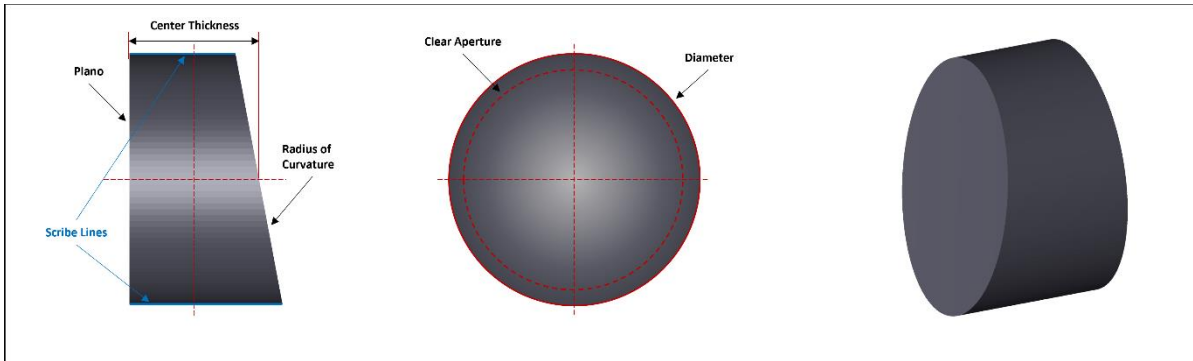


Figure 2: Off-axis parabolic (OAP) mirror general layout

The cosmetic quality of the polished optical surfaces is specified to be 10-5 for all mirrors and shall be verified using MIL-PRF-13830B as a guideline. Edges shall have 0.5mm bevels at 45 degrees. Any blemishes, scratches or other damage to the polished surface that do not meet specs shall be re-polished. The specification on surface micro-roughness is < 1 nm RMS over a 1 mm² area.

The optical coating shall be Protected Aluminum (AlMgF₂) with an average reflectance of greater than 90 percent over the waveband of 400-750 nm. It shall not fall below 85 percent anywhere within the bandpass. The vendor shall provide reflectance data in hard and soft copies along with data files for s-, p-, and un-polarized light at both normal incidence and 20-degree angle of incidence on Zerodur coupons prior to the actual mirror coating run(s). Enhancement layers are not acceptable. After QC tests are performed on the coupons, vendor is asked to send them to UA for additional testing. The optical surface shall be properly cleaned prior to coating. It shall be free of foreign debris. If an additional coating run is needed, the original coating shall be completely removed, and the surface cleaned prior to re-coat. The cleaning and coating processes shall not damage in any way the mirror surfaces. The coating shall be free of scratches, digs, pits, pinholes, foreign matter, defects, or visible non-uniformities as defined in MIL-PRF-13830B. The mirrors shall be coated over the entire optical surface area.

Both hardness and adhesion shall be verified using procedures defined in MIL-M-13508C: namely the 'cloth test' and the 'tape test'. The hardness of the coating shall be tested by using a dry cloth and hand rubbing the coated witness surface. No signs of scratches or other damage should be seen. Similarly, the adhesion of the coating to the glass coupon shall be tested with the 'tape test'. A piece of cellulose tape shall be attached and then slowly removed to test adhesion. The coating shall meet the performance specifications under all the environmental conditions specified in Table 6 for a minimum of five (5) years. If the vendor cannot meet this durability timeframe, they are requested to specify their own.

Optical Parameter	OAP 1	OAP 2A & 2B	OAP 3A & 3B	OAP 4	OAP 5
Comments	OAP 2A&B same ROC different OAD, OAP 4&5 same ROC & OAD different diameter				
Material	ULE or Zerodur or ClearCeram-Z: same substrate for all mirrors				
Diameter [mm]	50.0 +0 / -0.1	25.4 +0 / -0.1 (exception for OAP 2A & 5, see Figures 4 & 9)			
Center Thickness [mm]	25.0 ± 0.25	12.7 ± 0.25			
Clear Aperture [%]	> 85				
Radius of Curvature [mm]	1000.2 ± 0.1%	200 ± 0.1%	3A: 142 ± 0.1% 3B: 292 ± 0.1%	200 ± 0.1%	200 ± 0.1%
Conic Constant	-1.000				
Center-to-Center Off-Axis Distance [mm]	136.4	2A: 30.0 2B: 20.0	3A: 34.2 3B: 55.2	72.0	72.0
Wavefront Error [nm RMS]	2				
Surface 2D PSD (ABC model)	$A = 4.14E^{-3} \text{ nm}^2/(\text{c/m})^2$, $B = 10 \text{ c/m}$, $C = 2.65$				
Surface Quality	10-5				
Surface Roughness [nm]	< 1				
Coating Type	Protected aluminum (AlMgF ₂), no enhancement layers				
Coating Angle of Incidence [°]	0 – 20				
Coating Waveband [nm]	400 – 750				
Average Reflectance [%]	> 90				
Absolute Reflectance [%]	> 85				
Bevel	0.5 mm x 45°				
Parent Vertex Scribe Lines	Mark thin and thick edges with etched scribe line pointing to parent vertex axis, ± 0.5°				
Edge Surface Finish	Ground				
Back Surface Polish	Inspection-level				
Quantity	2	2 & 2	2 & 2	3	

Table 2: Mirror specification summary for OAP 1-5 mirrors

Optical Parameter	OAP 6	OAP 7	OAP 8	OAP 9	OAP 10
Comments	OAP 6-10 have the same general requirements, OAP 8 is identical to OAP 4, OAP 9 is identical to OAP 10				
Material	ULE or Zerodur or ClearCeram-Z: same substrate for all mirrors				
Diameter [mm]	25.4 +0 / -0.1				
Center Thickness [mm]	12.7 ± 0.25				
Clear Aperture [%]	> 85				
Radius of Curvature [mm]	900 ± 0.1%	400 ± 0.1%	200 ± 0.1%	280 ± 0.1%	280 ± 0.1%
Conic Constant	-1.000				
Center-to-Center Off-Axis Distance [mm]	150.5	70.5	72.0	60.0	60.0
Wavefront Error [nm RMS]	2				
Surface 2D PSD (ABC model)	A = 4.14E ⁻³ nm ² /(c/m) ² , B = 10 c/m, C = 2.65				
Surface Quality	10-5				
Surface Roughness [nm]	< 1				
Coating Type	Protected aluminum (AlMgF ₂), no enhancement layers				
Coating Angle of Incidence [°]	0 – 20				
Coating Waveband [nm]	400 – 750				
Average Reflectance [%]	> 90				
Absolute Reflectance [%]	> 85				
Bevel	0.5 mm x 45°				
Vertex Fiducial Scribe Lines	Mark thin and thick edges with etched scribe line pointing to parent vertex axis, ± 0.5°				
Edge Surface Finish	Ground				
Back Surface Polish	Inspection-level				
Quantity	3				

Table 3: Mirror specification summary for OAP 6-10 mirrors

Optical Parameter	FM 1	FM 2	SM 1
Comments	FM1 has the same requirement as FM2 different diameter, SM1 has same requirements to OAP mirrors		
Material	ULE or Zerodur or ClearCeram-Z: same substrate for all mirrors		
Diameter [mm]	50.0 +0 / -0.1	25.4 +0 / -0.1	25.4 +0 / -0.1
Center Thickness [mm]	12.5 ± 0.25	6.35 ± 0.25	12.7 ± 0.25
Clear Aperture [%]	> 85		
Radius of Curvature [mm]	-		280 ± 0.1%
Conic Constant	-		
Center-to-Center Off-Axis Distance [mm]	-		21.0
Wavefront Error [nm RMS]	2		
Surface 2D PSD (ABC model)	A = 4.14E ⁻³ nm ² /(c/m) ² , B = 10 c/m, C = 2.65		
Surface Quality	10-5		
Surface Roughness [nm]	< 1		
Coating Type	Protected aluminum (AlMgF ₂), no enhancement layers		
Coating Angle of Incidence [°]	0 – 20		
Coating Waveband [nm]	400 – 750		
Average Reflectance [%]	> 90		
Absolute Reflectance [%]	> 85		
Bevel	0.5 mm x 45°		
Vertex Fiducial Scribe Lines	-		
Edge Surface Finish	Ground		
Back Surface Polish	Inspection-level		
Quantity	2	3	

Table 4: Mirror specification summary for Flat mirrors 1-2 and Spherical mirror 1

The specifications described in Tables 2-4 satisfy the project requirements. However, the vendor is asked to work toward improved performance, barring significant cost increase, defined as ‘goals’ with the following specs:

Optical Parameter	Requirement	Goal
Clear Aperture [%]	>85%	>90%
Wavefront Error [nm]	2	0.5
Average / Absolute Reflectance [%]	90 / 85	93 / 88

Table 5: Specifications defined with Requirements and Goals

5. Environmental Specifications

Since the mirrors shall be tested at room temperature and at both ambient & vacuum pressure, all specifications listed in Tables 2-4 shall be preserved under the environmental conditions listed in Table 6 as defined in MIL-M-13508C and ISO-19683.

	Requirement
Survival Temperature [°C]	-25 to +60
Operating Temperature [°C]	+15 to +35
Survival Pressure [Torr]	0 to 760
Operating Pressure [Torr]	1E-8
Survival Humidity [%]	0 to 100
Operating Humidity [%]	0

Table 6: Survival and operating environmental conditions

The vendor shall demonstrate that the mirrors meet all specifications via quality control: visual microscope inspection, interferometric testing, and/or CMM metrology. Test measurements in the form of hard and soft copies shall be made available along with test data files. The vendor shall provide documentation detailing the polishing procedure, final testing, and final cleaning. A certificate of compliance shall accompany each mirror. Vendor schedules shall begin with receipt of the purchase order. It shall end after completion of packing of the last mirror in preparation for shipment. The vendor shall be responsible for safely packing and protecting the finished optics. They shall assume responsibility for the risk of shipping and properly insure the shipment. Shipping charges shall be FOB Tucson. Vendors are encouraged to suggest alternate procedures or provide options where strict adherence to these requirements is not possible. The possibility of a partial shipment is reserved by the University. Vendor is asked to provide a partial delivery schedule if necessary. Additionally, the vendor is asked to provide an expedite schedule that includes the expedite fee and reduced leadtime.

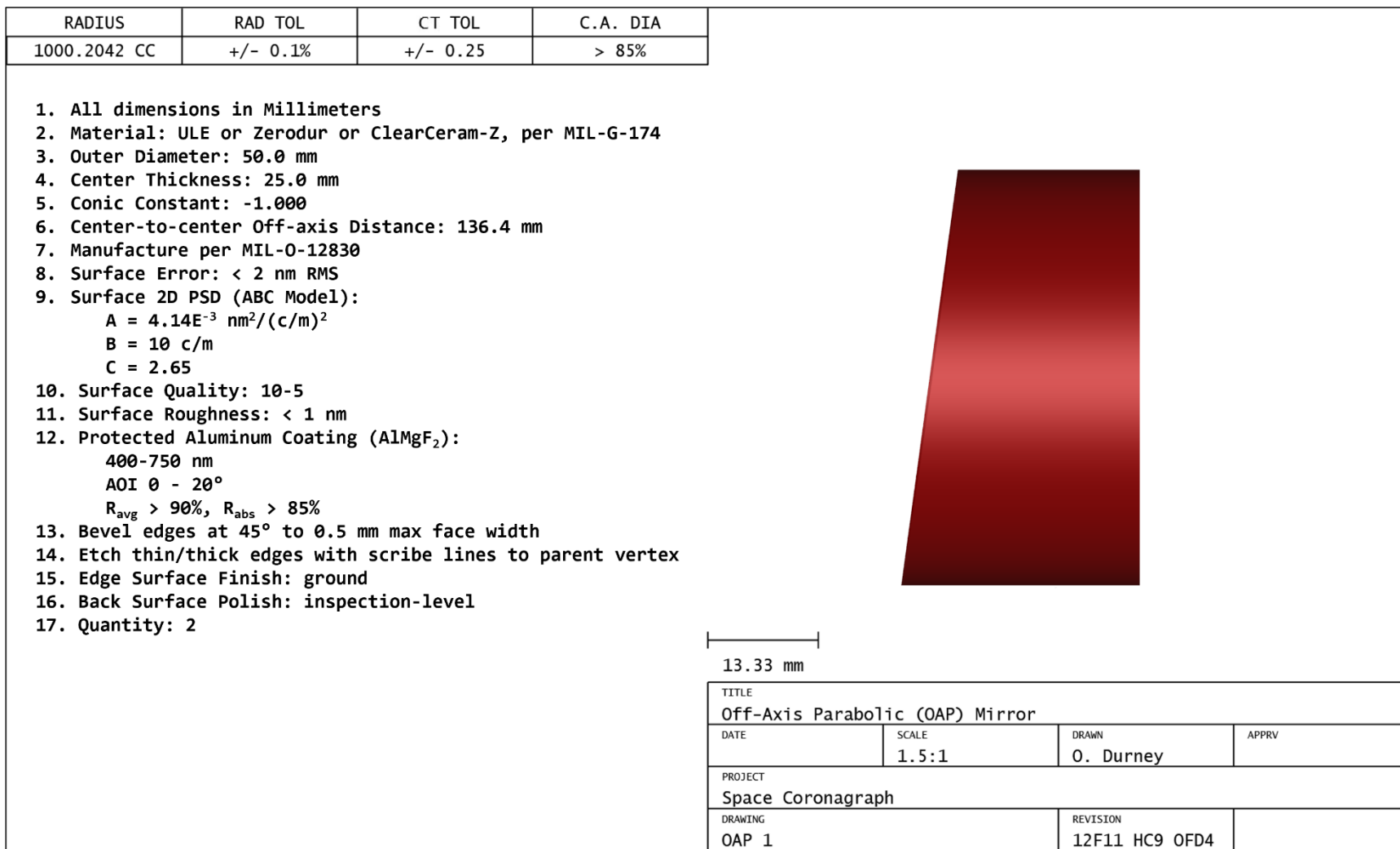


Figure 3: Off-axis parabolic (OAP) mirror 1 drawing

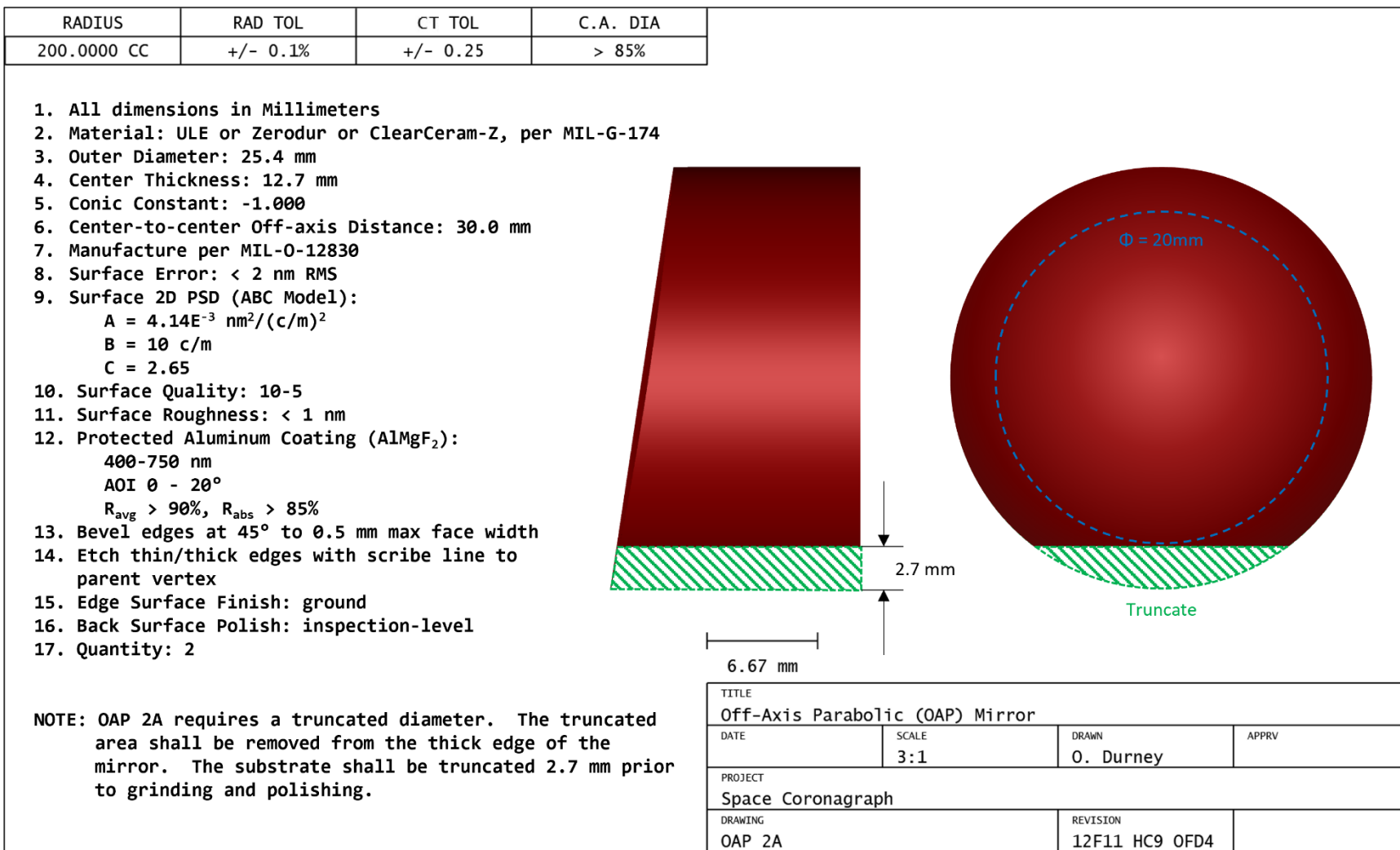


Figure 4: Off-axis parabolic (OAP) mirror 2A drawing

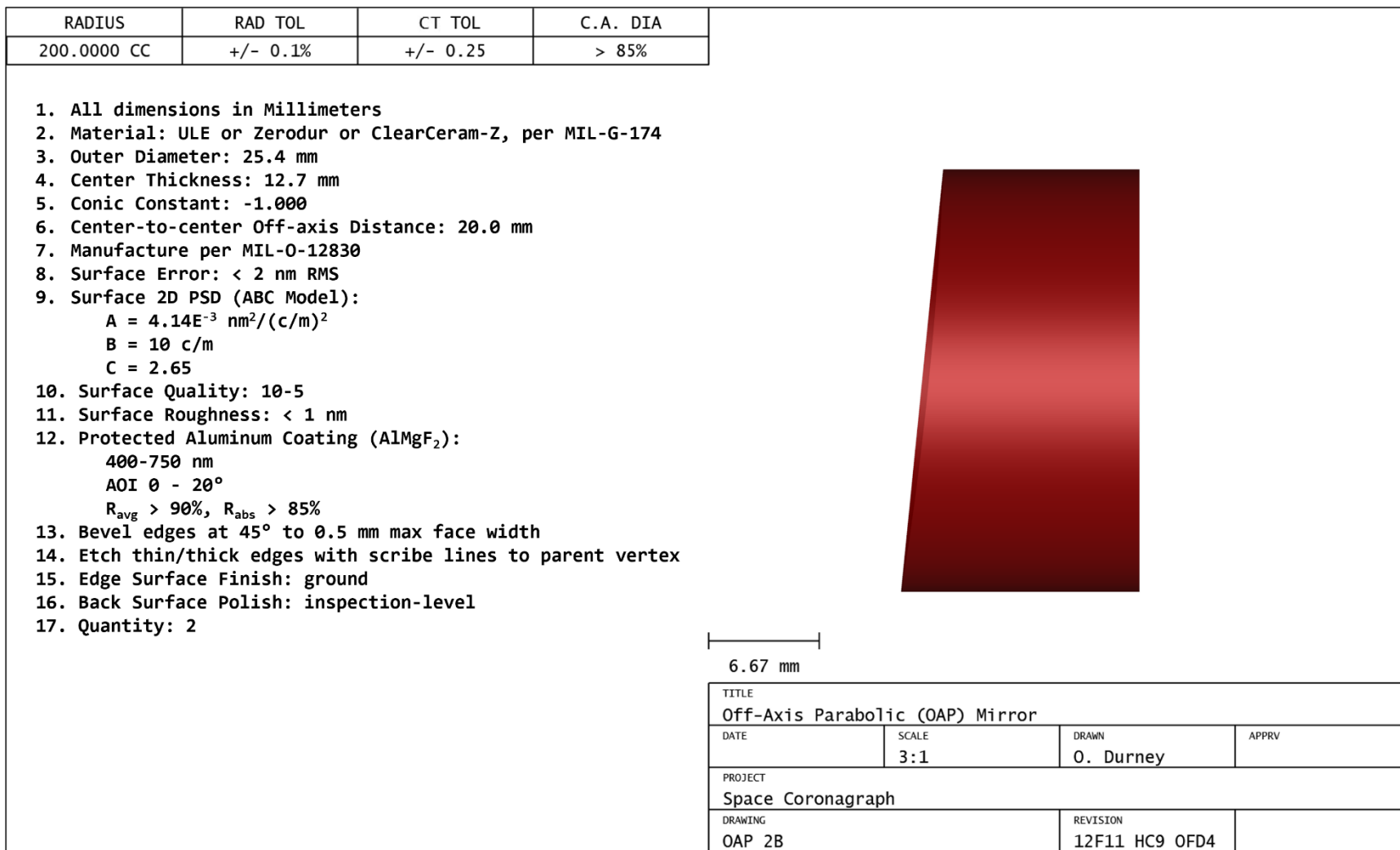


Figure 5: Off-axis parabolic (OAP) mirror 2B drawing

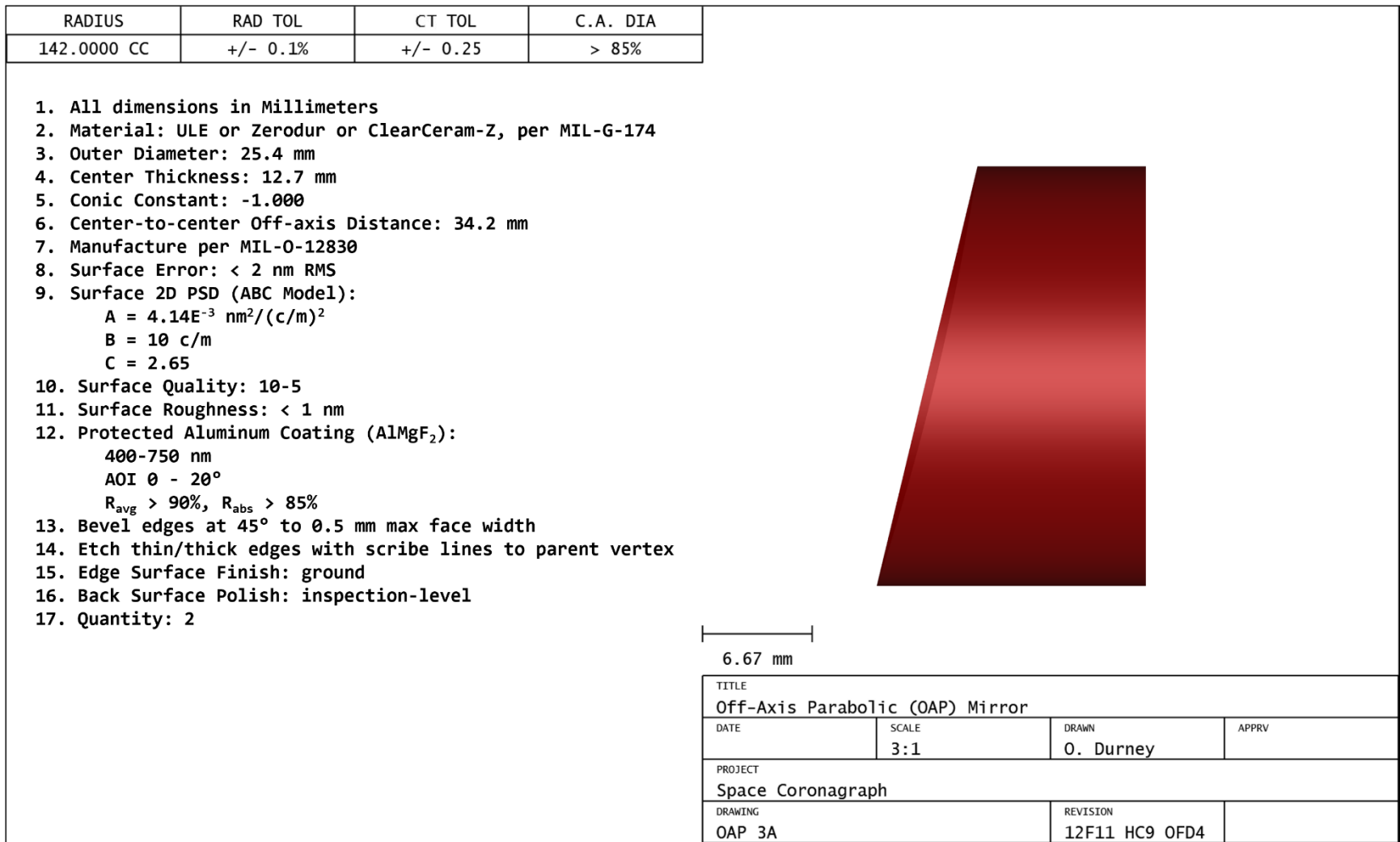


Figure 6: Off-axis parabolic (OAP) mirror 3A drawing

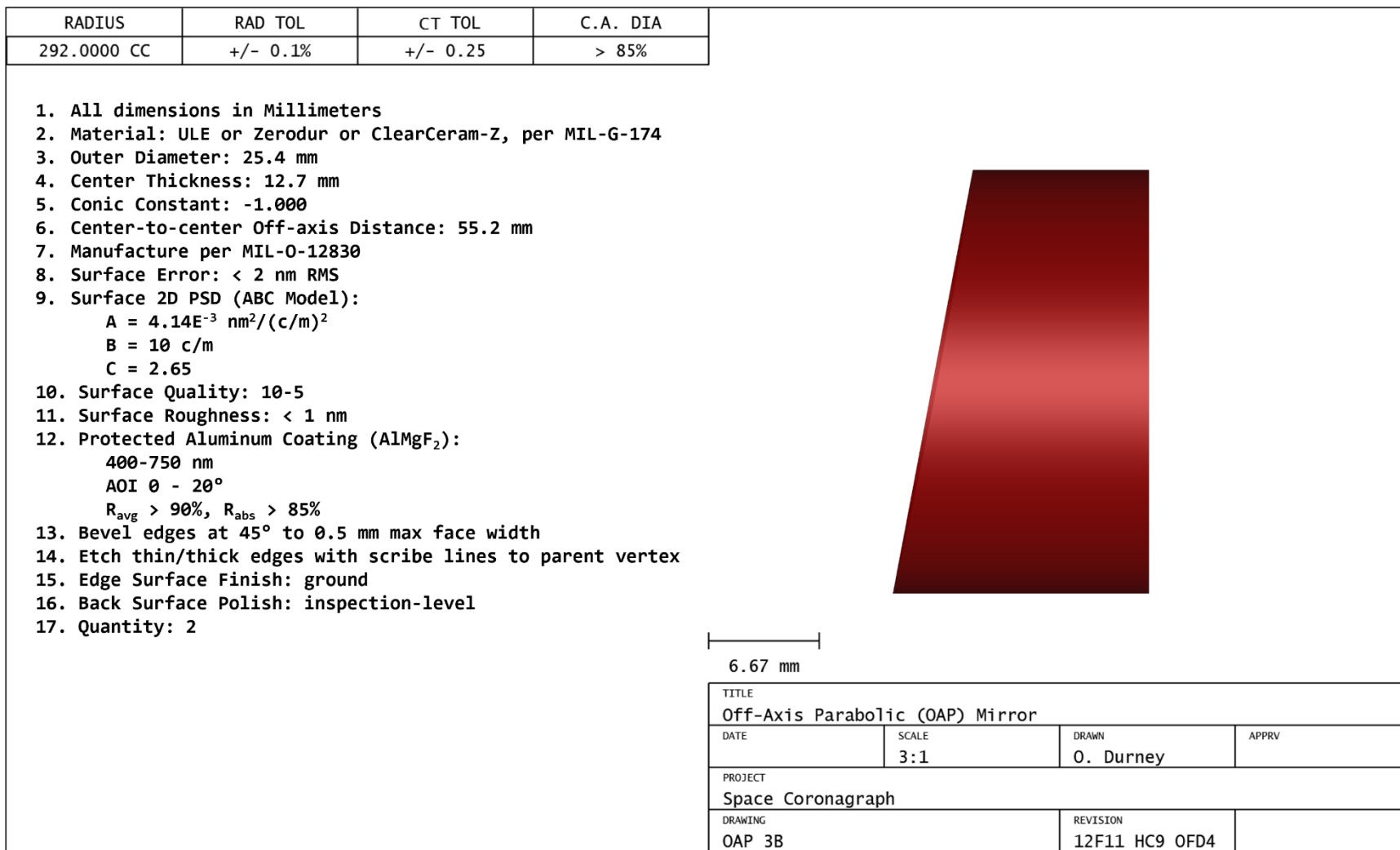


Figure 7: Off-axis parabolic (OAP) mirror 3B drawing

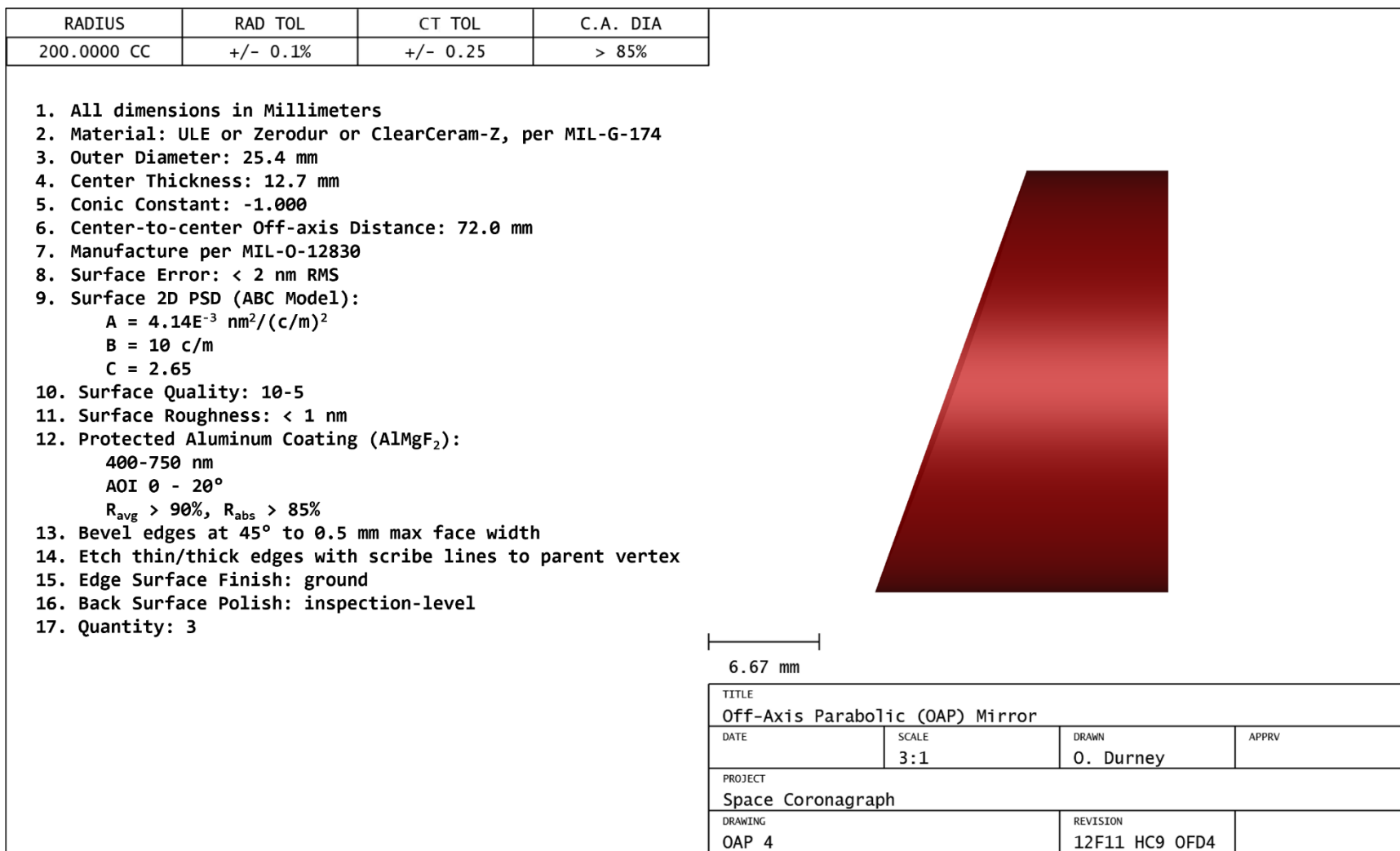


Figure 8: Off-axis parabolic (OAP) mirror 4 drawing

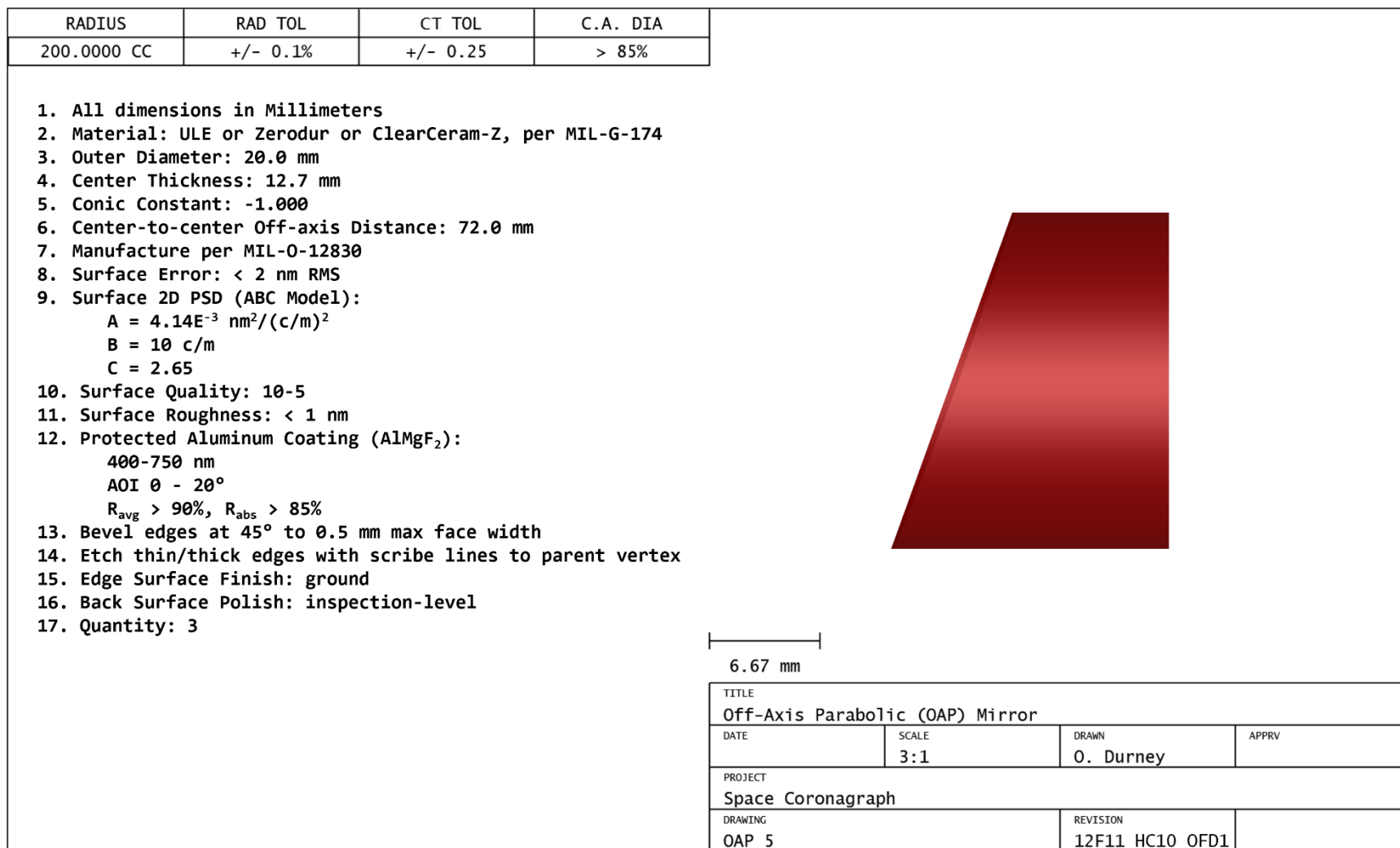


Figure 9: Off-axis parabolic (OAP) mirror 5 drawing

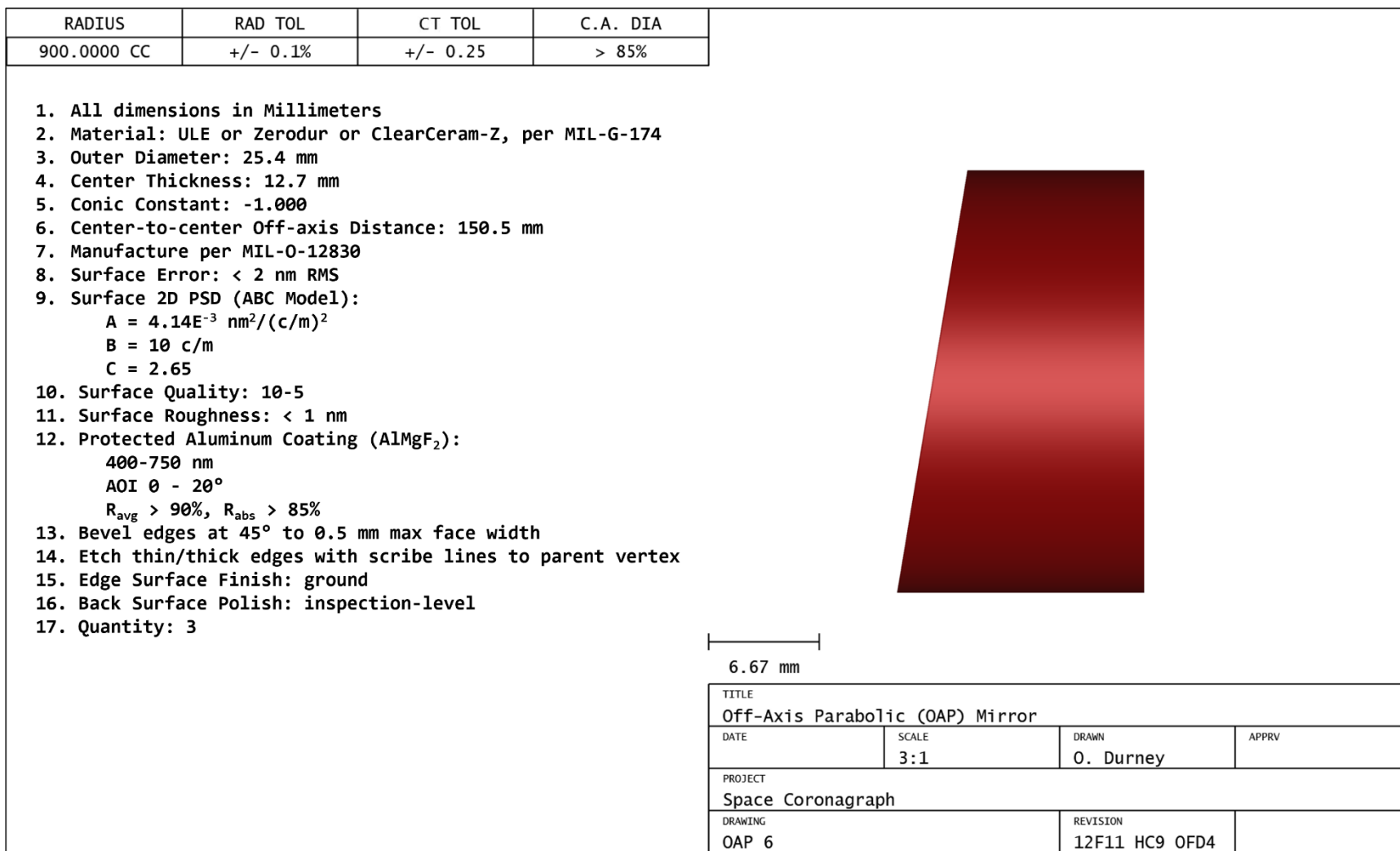


Figure 10: Off-axis parabolic (OAP) mirror 6 drawing

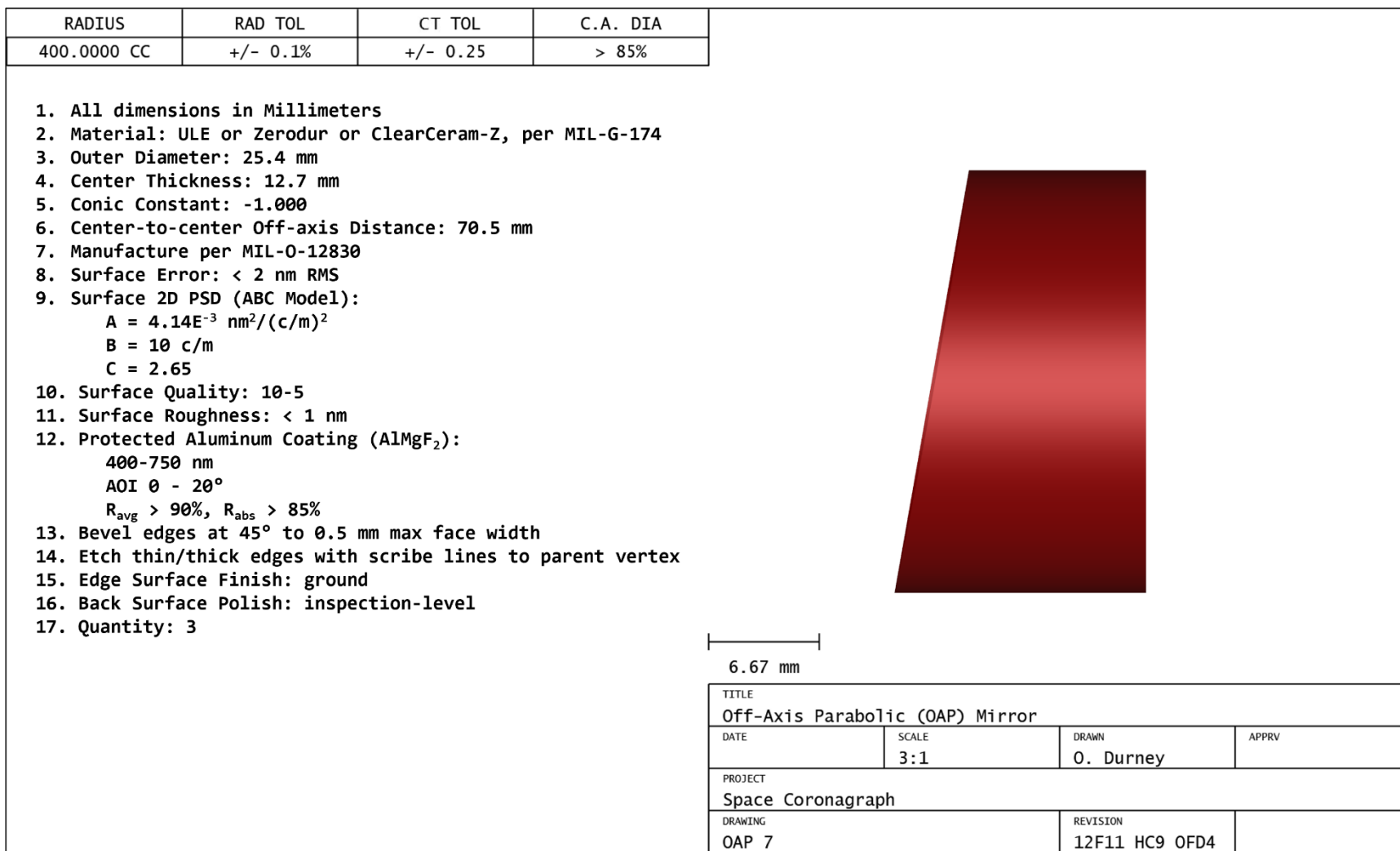


Figure 11: Off-axis parabolic (OAP) mirror 7 drawing

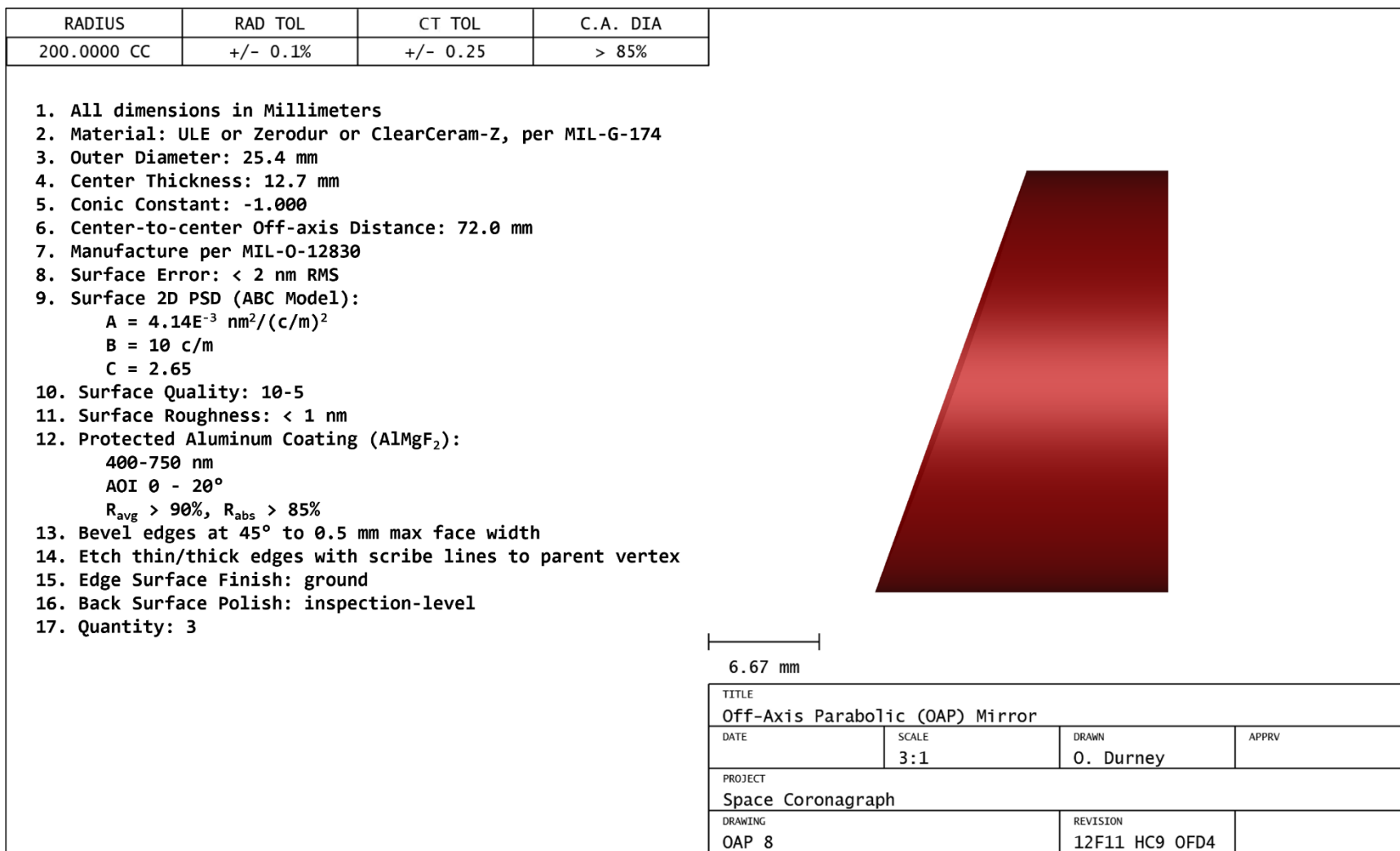


Figure 12: Off-axis parabolic (OAP) mirror 8 drawing

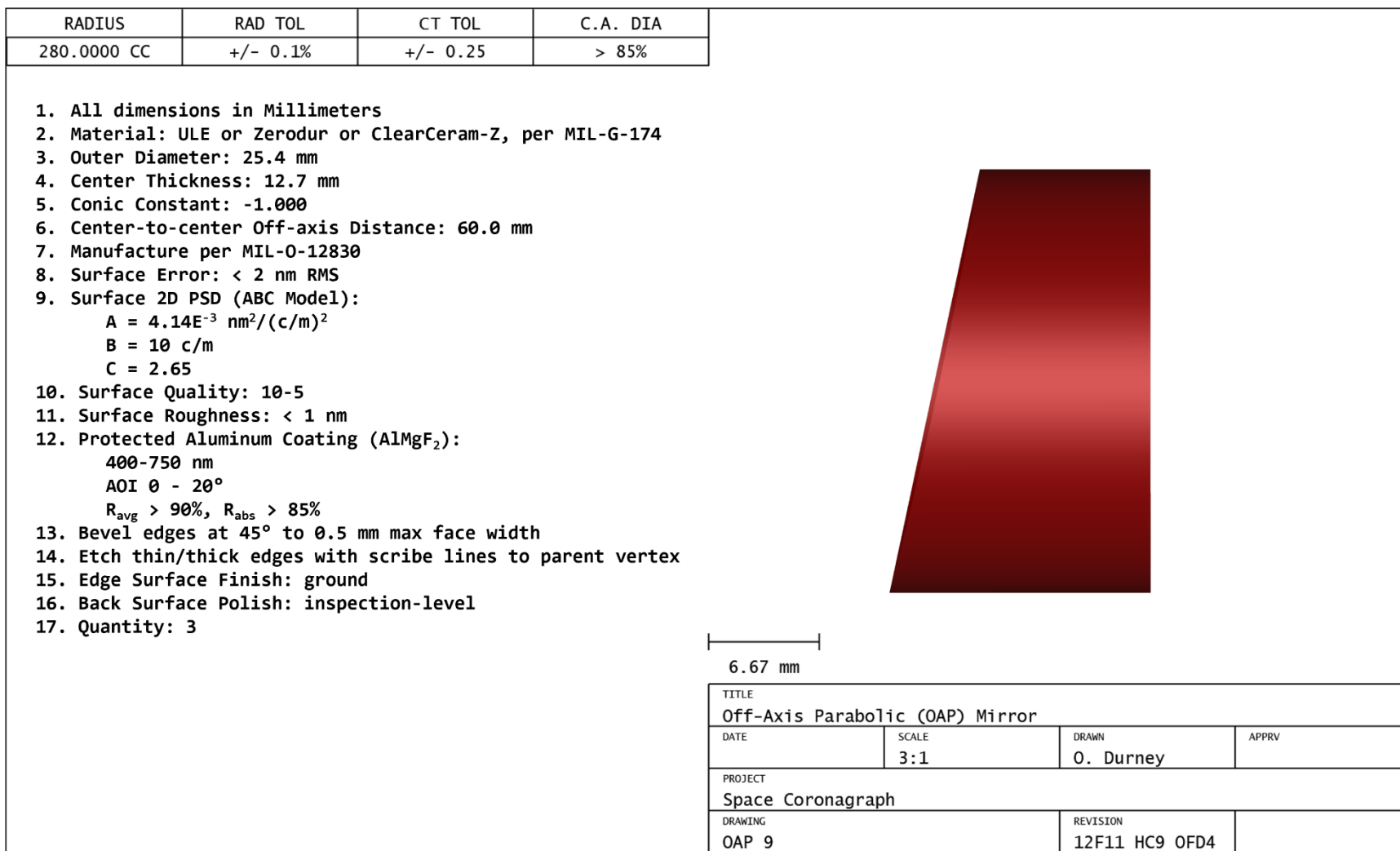


Figure 13: Off-axis parabolic (OAP) mirror 9 drawing

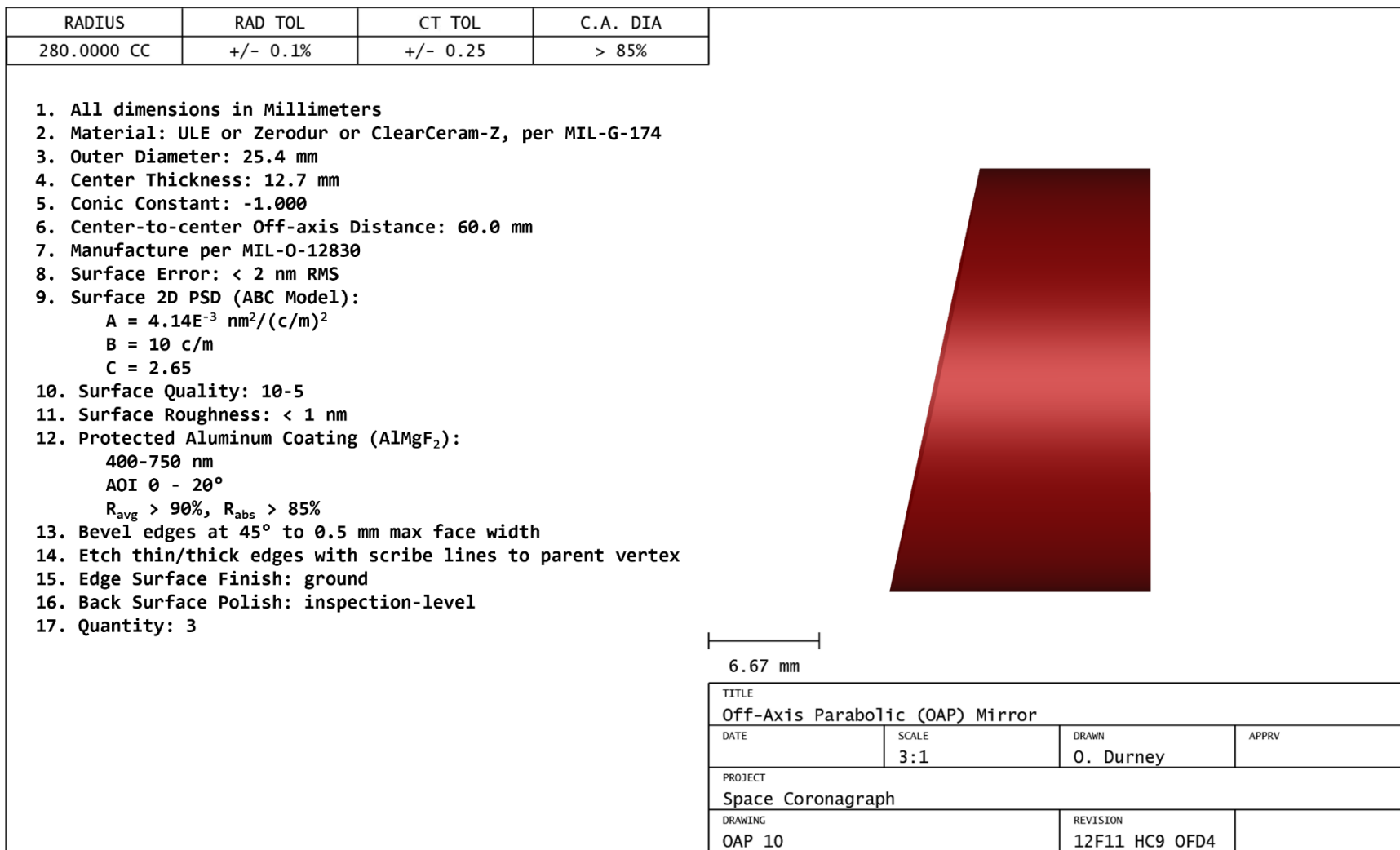


Figure 14: Off-axis parabolic (OAP) mirror 10 drawing

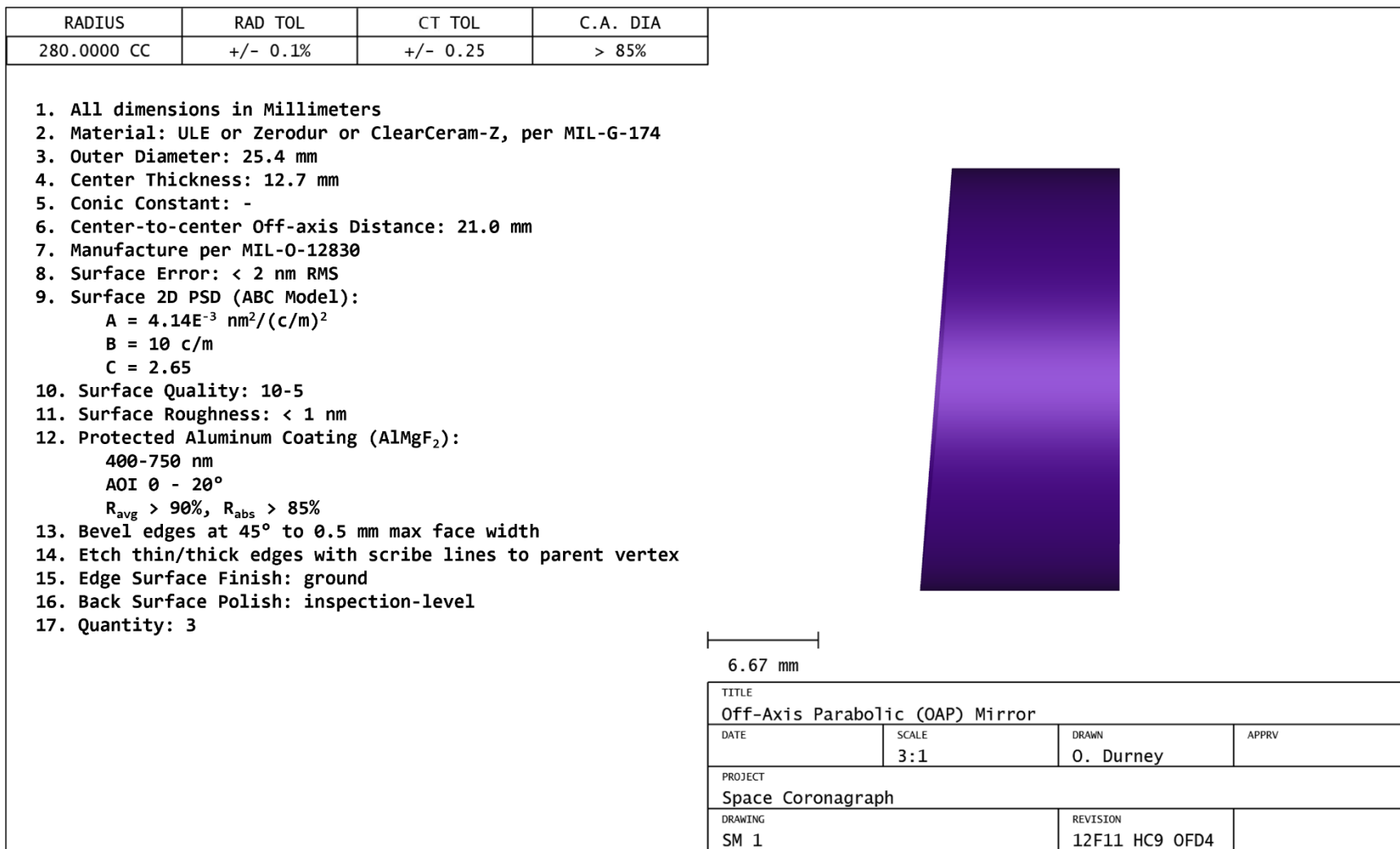
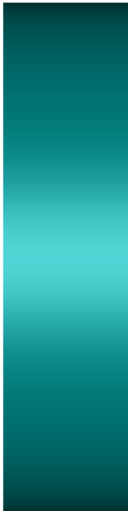
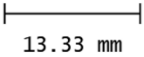


Figure 15: Spherical mirror 1 drawing

RADIUS	RAD TOL	CT TOL	C.A. DIA
PLANO	+/- 0.1%	+/- 0.25	> 85%

1. All dimensions in Millimeters
2. Material: ULE, Zerodur, or Clear Ceram-Z, per MIL-G-174
3. Outer Diameter: 50.0 mm
4. Center Thickness: 12.5 mm
5. Conic Constant: -
6. Center-to-center Off-axis Distance: -
7. Manufacture per MIL-O-12830
8. Surface Error: < 2 nm RMS
9. Surface 2D PSD (ABC Model):
 - A = $4.14E^{-3} \text{ nm}^2/(\text{c/m})^2$
 - B = 10 c/m
 - C = 2.65
10. Surface Quality: 10-5
11. Surface Roughness: < 1 nm
12. Protected Aluminum Coating (AlMgF₂):
 - 400-750 nm
 - AOI θ - 20°
 - R_{avg} > 90%, R_{abs} > 85%
13. Bevel edges at 45° to 0.5 mm max face width
14. Edge Surface Finish: ground
15. Back Surface Polish: inspection-level
16. Quantity: 2





13.33 mm

TITLE			
Off-Axis Parabolic (OAP) Mirror			
DATE	SCALE	DRAWN	APPRV
	1.5:1	O. Durney	
PROJECT			
Space Coronagraph			
DRAWING		REVISION	
FM 1		12F11 HC9 OFD4	

Figure 16: Flat mirror 1 drawing

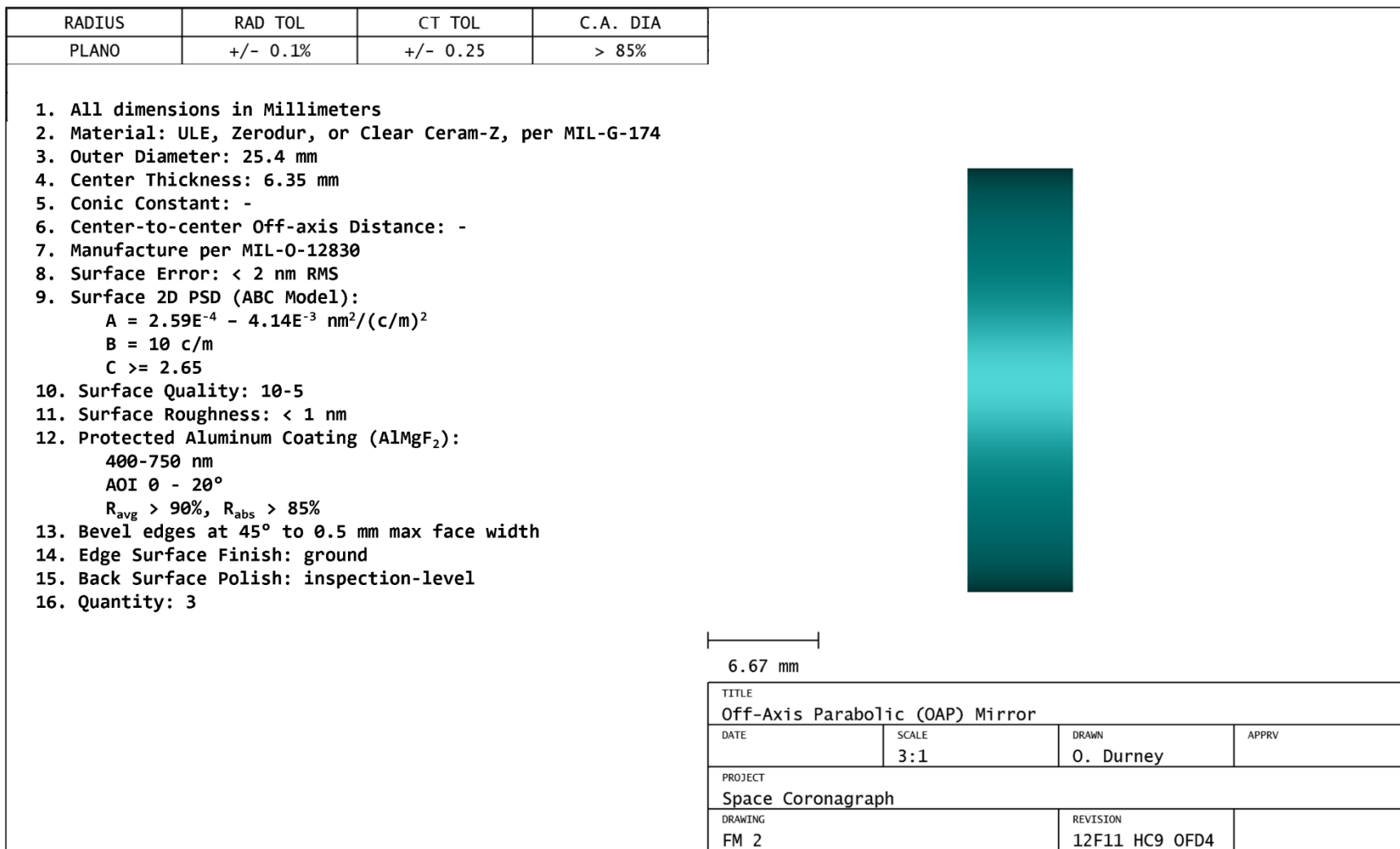


Figure 17: Flat mirror 2 drawing