

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) requests a quotation for the grinding, polishing, coating, and testing of custom off-axis parabolic (OAP) mirrors and spare units. The optics are part of a space-based, high-contrast coronagraph. All optics and coatings shall be vacuum compatible.

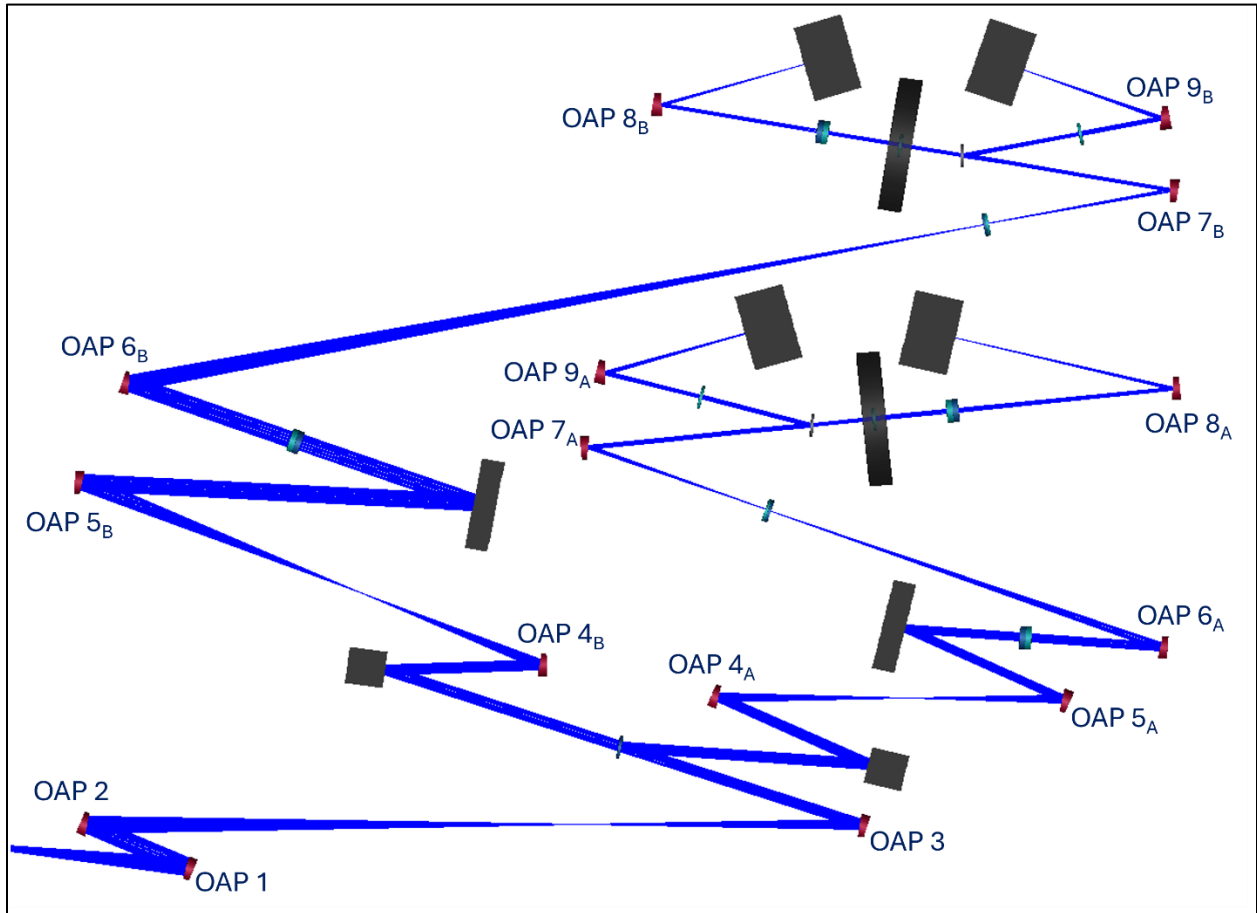


Figure 1: Illustration of optical design (OAP mirrors in red)

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. 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 durable, reflective coating suitable for the environmental conditions listed in Table 7. There are fifteen (15) OAP mirrors. The program requires the procurement of quantity two (2) for each OAP mirror: one (1) set for flight operations and one (1) spare set. OAP4_A and OAP4_B are identical. OAP7_A and OAP7_B have the same ROC but different OADs. OAP9_A and OAP9_B are identical. Note, OAP4_A, OAP4_B, OAP7_A, & OAP7_B all have the same ROC and could be cored from the same parent parabola as a cost savings.

3. Deliverables

This RFP shall include the following items:

Line Item	Quantity	Description
01	2	Set of fifteen (15) OAP mirrors
02	1	OAP mirror certificate(s) of conformity
03	1	Reflective coating documentation
04	1	Quality control / metrology / testing report(s)
05	1	Box(es) for storage and transport

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 >95% of the outer diameter as specified in Tables 2-4. The minimum edge thickness (ET) for each OAP mirror shall be 6.35mm for either a parent-child cored (wedged) mirror or a stand-alone (freeform) uniform edge mirror. All OAP radius of curvature tolerances shall be $\pm 0.1\%$. RMS surface error (SE) shall be defined as 2nm or less for OAP1 and OAP2. For OAP3, the RMS SE shall be 4nm or less. The remaining OAPs shall have an RMS SE of 5nm or less. Spatial frequency errors are specified in three (3) sampling lengths: Low Order, Mid Order, High Order (LO/MO/HO) with a surface RMS requirement for each range, see Table 5. All data sets and maps shall have a minimum resolution of 512 x 512.

The form factor for all OAP mirrors shall be chosen by the vendor to meet the specifications. For wedge, the back plano surface shall be orthogonal to the vertex axis of the parent parabola. For stand alone, the back plano surface orientation shall create a uniform edge thickness. The back surfaces shall have an inspection-level polish. The edge surfaces shall have a ground finish. The vendor shall mark the thin edge of each OAP with one (1) etched scribe line indicating the direction of the parent vertex. A pencil or marker scribe line is not acceptable. The scribe line shall be accurate to $\pm 0.5^\circ$.

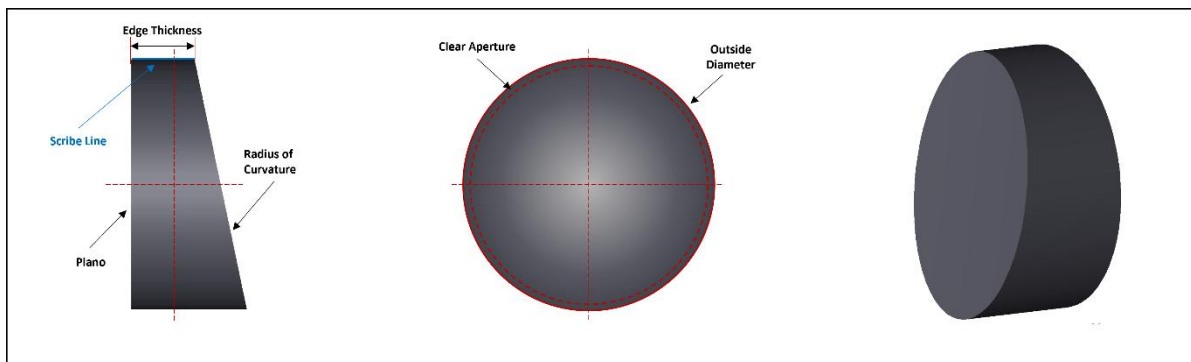


Figure 2: Wedge off-axis parabolic (OAP) mirror general layout

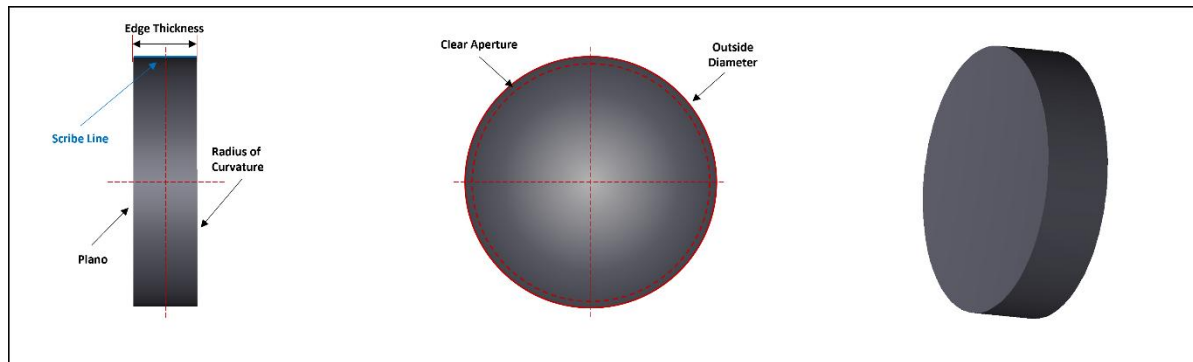


Figure 3: Stand-alone off-axis parabolic (OAP) mirror general layout

The cosmetic quality of the polished optical surfaces is specified to be 10-5 for OAP1-3 and 20-10 for the remaining OAP mirrors. It 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 < 0.4 nm RMS over a 1 mm² area for OAP1-3 and <1.0 nm RMS for the remaining OAP mirrors. A minimum of three (3) random locations shall be tested for each optic. Surface roughness shall be measured according to ISO-10110-8 (in the 1/2.5 μm^{-1} to 1/85 μm^{-1} spatial-frequency band) pre and post coating.

The optical coating shall be determined by the vendor. UA requests the best reflectance possible over an AOI range of 15-30° and over a waveband of 400-750 nm while maintaining a durability lifetime of at least three (3) years. The vendor shall provide reflectance data in hard and soft copies along with data files for s-, p-, and un-polarized light at both 15- and 30-degree angles of incidence on Zerodur coupons prior to the actual mirror coating run(s). Enhancement layers are 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 for each coating run 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 7 for a minimum of three (3) years. If the vendor cannot meet this durability timeframe, they are requested to specify their own.

Optical Parameter	OAP 1	OAP 2	OAP 3	OAP 4A	OAP 4B
Comments	OAP 4A & 4B are identical				
Material	ULE or Zerodur or ClearCeram-Z: same substrate for all mirrors				
Diameter [mm]	25.4 +0 / -0.1				
Edge Thickness [mm]	6.35 ± 0.25				
Clear Aperture [%]	> 95				
Radius of Curvature [mm]	580.8 ± 0.1%	1050.0 ± 0.1%	600.0 ± 0.1%	400.0 ± 0.1%	400.0 ± 0.1%
Conic Constant	-1.000				
Center-to-Center Off-Axis Distance [mm]	98.0 ± 0.2	213.7 ± 0.2	95.1 ± 0.2	84.0 ± 0.2	84.0 ± 0.2
Overall Surface Error [nm RMS]	2		4	5	
Spatial Frequency Breakdown	See Table 5				
Surface Quality	10-5			20-10	
Surface Roughness [nm]	< 0.4			< 1.0	
Coating Type	TBD by vendor				
Coating Angle of Incidence [°]	15 – 30				
Coating Waveband [nm]	400 – 750				
Average Reflectance [%]	Best reflectance over the waveband and AOI, durability > 3 years				
Absolute Reflectance [%]	Best reflectance over the waveband and AOI, durability > 3 years				
Bevel	0.5 mm x 45°				
Parent Vertex Scribe Line	Mark thin edge with etched scribe line pointing to parent vertex axis, ± 0.5°				
Edge Surface Finish	Ground				
Back Surface Polish	Inspection-level				
Quantity	2 each				
Leadtime	6-9 months				

Table 2: Mirror specification summary for OAP 1-4B mirrors

Optical Parameter	OAP 5A	OAP 5B	OAP 6A	OAP 6B	OAP 7A
Comments	OAP 7A & 7B have the same ROC, but different OADs				
Material	ULE or Zerodur or ClearCeram-Z: same substrate for all mirrors				
Diameter [mm]	25.4 +0 / -0.1				
Edge Thickness [mm]	6.35 ± 0.25				
Clear Aperture [%]	> 95				
Radius of Curvature [mm]	328.7 ± 0.1%	653.9 ± 0.1%	900.0 ± 0.1%	1800.0 ± 0.1%	400.0 ± 0.1%
Conic Constant	-1.000				
Center-to-Center Off-Axis Distance [mm]	69.0 ± 0.2	107.7 ± 0.2	120.2 ± 0.2	474.8 ± 0.2	88.9 ± 0.2
Overall Surface Error [nm RMS]	5				
Spatial Frequency Breakdown	See Table 5				
Surface Quality	20-10				
Surface Roughness [nm]	< 1.0				
Coating Type	TBD by vendor				
Coating Angle of Incidence [°]	15 – 30				
Coating Waveband [nm]	400 – 750				
Average Reflectance [%]	Best reflectance over the waveband and AOI, durability > 3 years				
Absolute Reflectance [%]	Best reflectance over the waveband and AOI, durability > 3 years				
Bevel	0.5 mm x 45°				
Parent Vertex Scribe Line	Mark thin edge with etched scribe line pointing to parent vertex axis, ± 0.5°				
Edge Surface Finish	Ground				
Back Surface Polish	Inspection-level				
Quantity	2 each				
Leadtime	6-9 months				

Table 3: Mirror specification summary for OAP 5A-7A mirrors

Optical Parameter	OAP 7B	OAP 8A	OAP 8B	OAP 9A	OAP 9B
Comments	OAP 7A & 7B have the same ROC, but different OADs, OAP 9A & 9B are identical				
Material	ULE or Zerodur or ClearCeram-Z: same substrate for all mirrors				
Diameter [mm]	25.4 +0 / -0.1				
Edge Thickness [mm]	6.35 ± 0.25				
Clear Aperture [%]	> 95				
Radius of Curvature [mm]	400.0 ± 0.1%	480.8 ± 0.1%	312.2 ± 0.1%	300.0 ± 0.1%	300.0 ± 0.1%
Conic Constant	-1.000				
Center-to-Center Off-Axis Distance [mm]	70.7 ± 0.2	81.0 ± 0.2	69.2 ± 0.2	80.2 ± 0.2	80.2 ± 0.2
Surface Error [nm RMS]	5				
Spatial Frequency Breakdown	See Table 5				
Surface Quality	20-10				
Surface Roughness [nm]	< 1.0				
Coating Type	TBD by vendor				
Coating Angle of Incidence [°]	15 – 30				
Coating Waveband [nm]	400 – 750				
Average Reflectance [%]	Best reflectance over the waveband and AOI, durability > 3 years				
Absolute Reflectance [%]	Best reflectance over the waveband and AOI, durability > 3 years				
Bevel	0.5 mm x 45°				
Parent Vertex Scribe Line	Mark thin edge with etched scribe line pointing to parent vertex axis, ± 0.5°				
Edge Surface Finish	Ground				
Back Surface Polish	Inspection-level				
Quantity	2 each				
Leadtime	6-9 months				

Table 4: Mirror specification summary for OAP 7B-9B

The overall surface error (SE) specification can be broken down into specific spatial frequency sampling lengths in μm (low order, mid order, high order) and their respective RMS values in nm. The spatial ranges are defined as LO ($>10\text{mm}$), MO ($1-10\text{mm}$), HO ($85\mu\text{m}-1\text{mm}$), and SR ($2.5-85\mu\text{m}$). SE is the RSS of the three (3) ranges and the surface roughness (SR) as shown in Table 5. Also shown are the 2D ABC models for each OAP grouping. Note, OAP3 is specified as the sum of two (2) PSD ABC models.

OAP	LO ($> 10\text{mm}$)	MO ($1 - 10\text{mm}$)	HO ($85\mu\text{m} - 1\text{mm}$)	SR ($2.5 - 85\mu\text{m}$)
1 - 2	0.7	1.6	0.9	0.4
3	4.0	0.5	0.7	0.4
4 - 9	1.7	4.0	2.2	1.0
1 - 2	2D PSD ABC Model: $A = 1.678\text{E}^{-3} \text{ nm}^2/(\text{c/m})^2$, $B = 154 \text{ c/m}$, $C = 2.7$			
3	2D PSD ABC Model 1: $A_1 = 1.97\text{E}^{-3} \text{ nm}^2/(\text{c/m})^2$, $B_1 = 150 \text{ c/m}$, $C_1 = 7$ 2D PSD ABC Model 2: $A_2 = 3.19\text{E}^{-3} \text{ nm}^2/(\text{c/m})^2$, $B_2 = 1500 \text{ c/m}$, $C_2 = 2.7$			
4 - 9	2D PSD ABC Model: $A = 1.05\text{E}^{-3} \text{ nm}^2/(\text{c/m})^2$, $B = 154 \text{ c/m}$, $C = 2.7$			

Table 5: PSD LO / MO / HO specification breakdown

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 [%]	$>95\%$	$>97\%$
SE [nm] for OAP1-2, (3), & {OAP4-9}	2 (4) {5}	1 (3) {4}
SR [nm] for OAP1-3 & (OAP4-9)	<0.4 (<1.0)	<0.2 (<0.5)
Leadtime	9 months	6 months

Table 6: 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 7 as defined in MIL-M-13508C and ISO-19683.

Environmental Spec	Requirement
Survival Temperature [$^{\circ}\text{C}$]	-25 to +60
Operating Temperature [$^{\circ}\text{C}$]	+15 to +35
Survival Pressure [Torr]	0 to 760
Operating Pressure [Torr]	$< 1\text{E}-8$
Survival Humidity [%]	0 to 100
Operating Humidity [%]	0

Table 7: Survival and operating environmental conditions

The survival specs shown are estimated worst-case values expected during laboratory testing and launch. Operating specs are estimates for on-orbit operation. 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 an expedite fee and reduced leadtime, if possible.

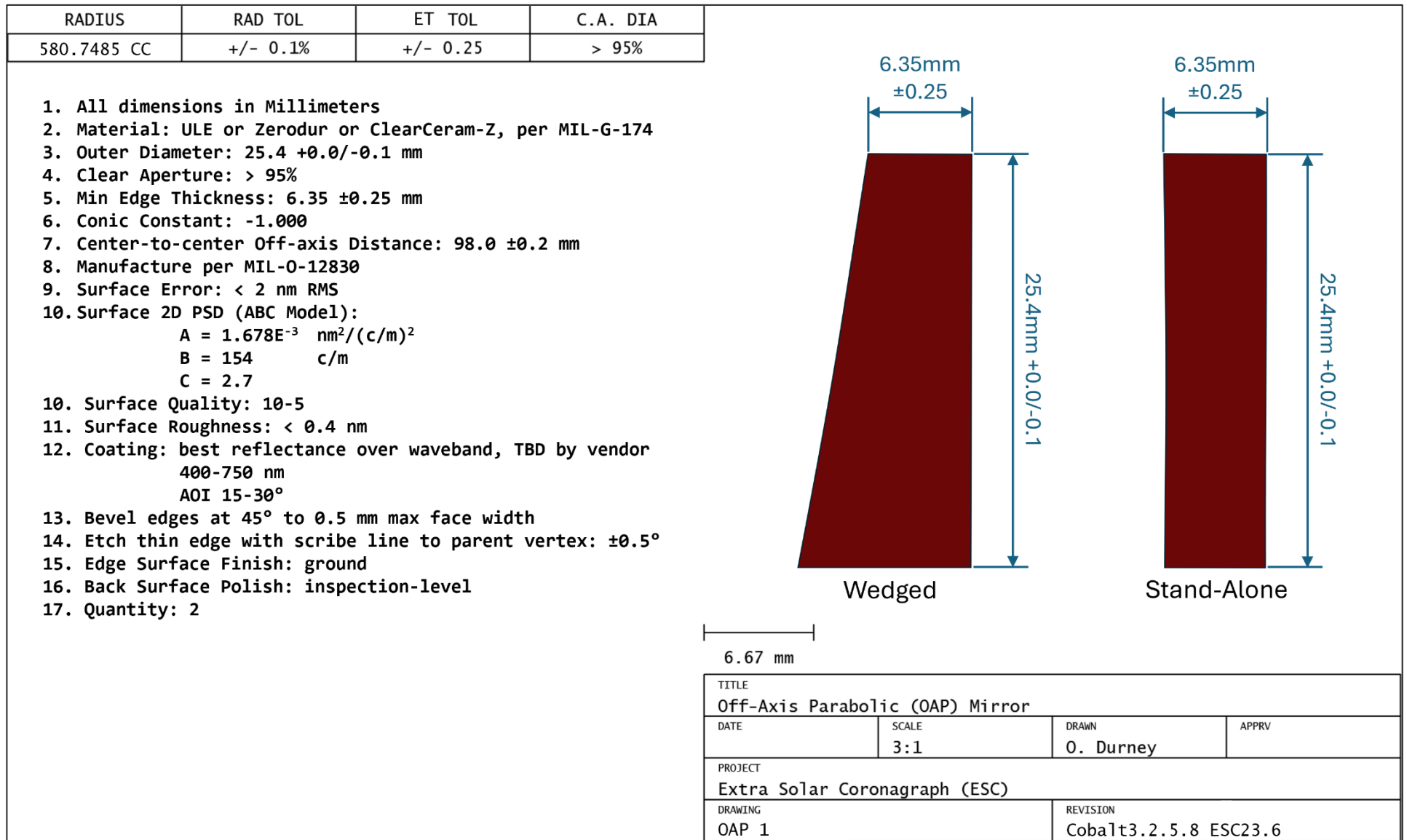


Figure 4: Off-axis parabolic mirror, OAP 1 drawing

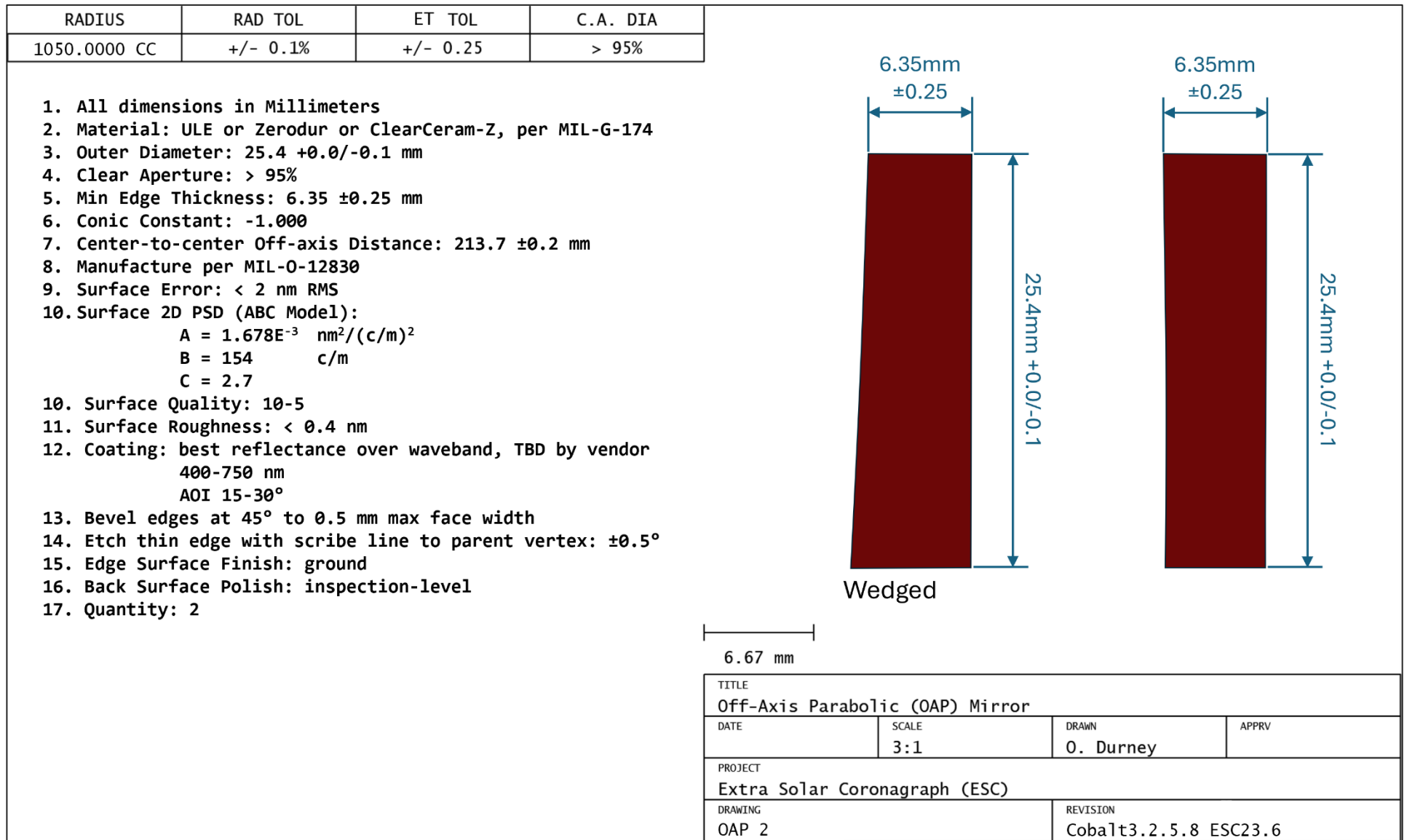


Figure 5: Off-axis parabolic mirror, OAP 2 drawing

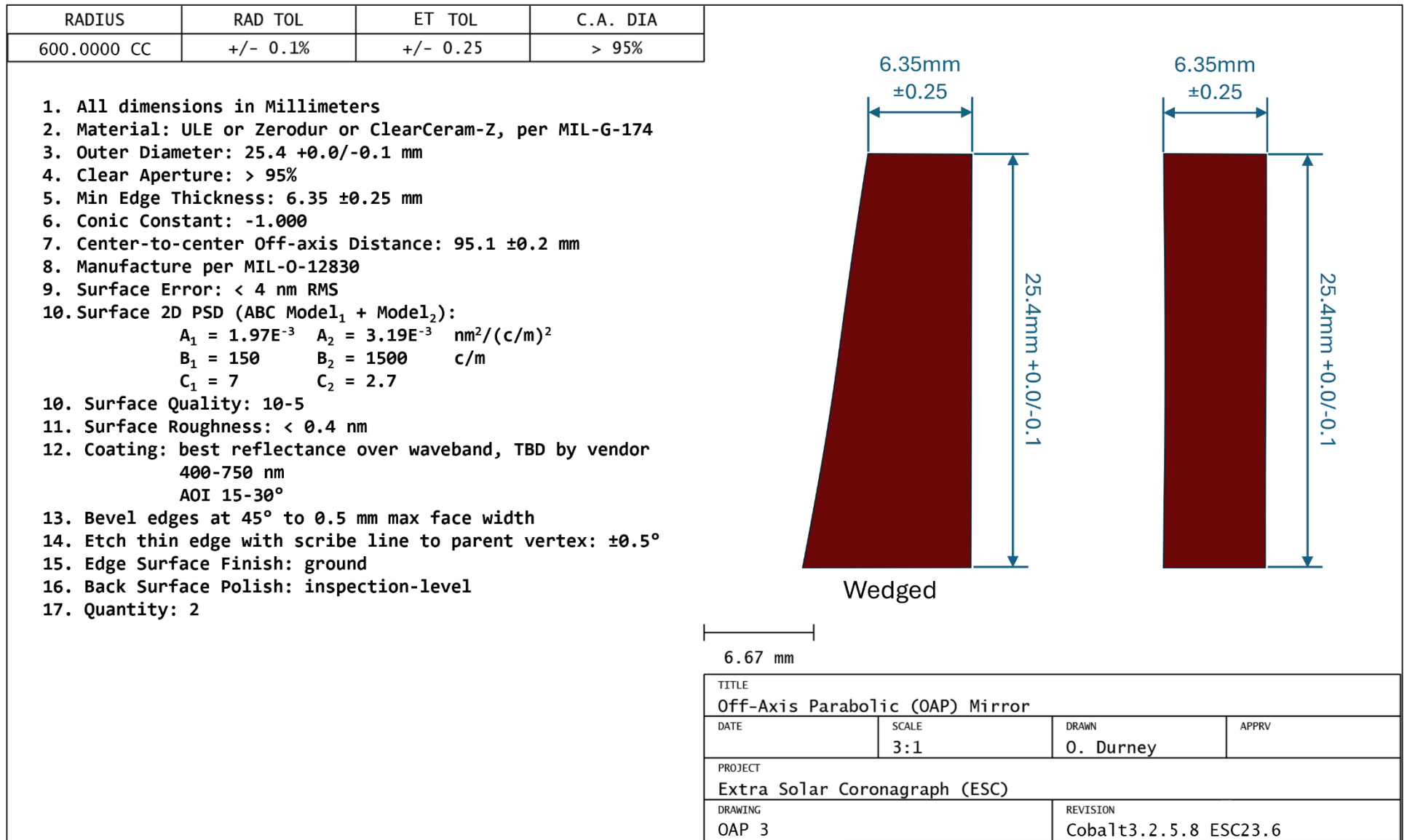


Figure 6: Off-axis parabolic mirror, OAP 3 drawing

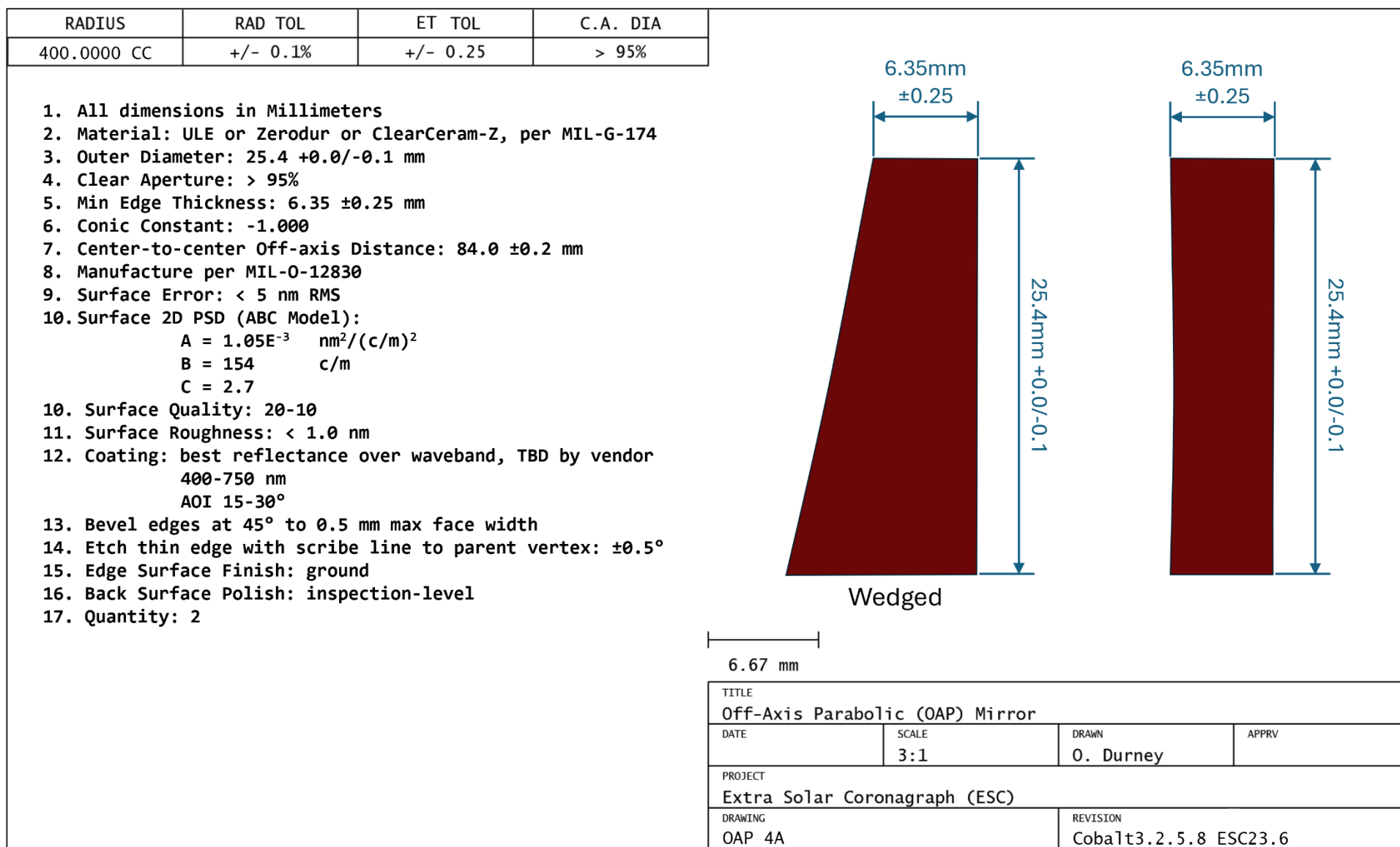


Figure 7: Off-axis parabolic mirror, OAP 4A drawing

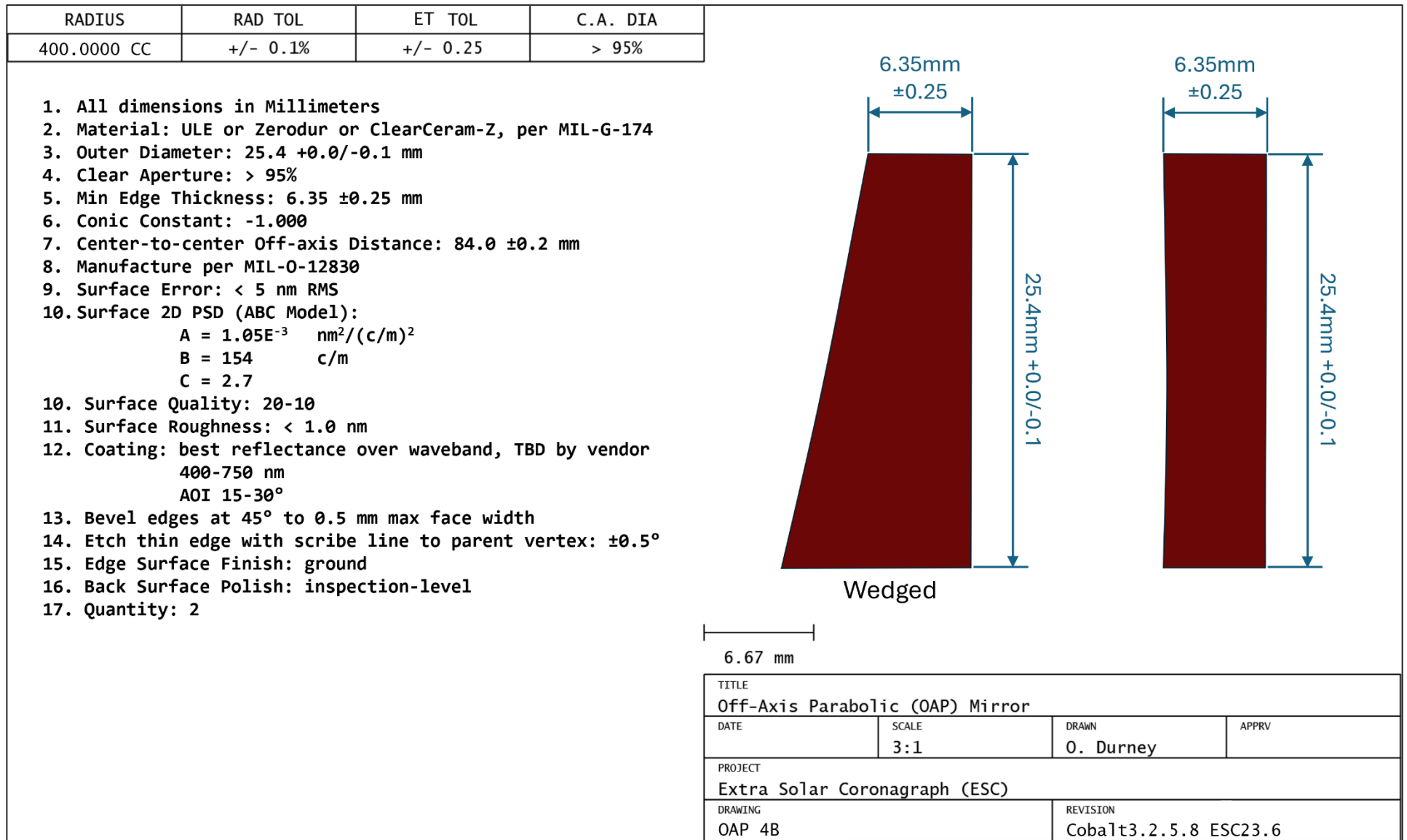


Figure 8: Off-axis parabolic mirror, OAP 4B drawing

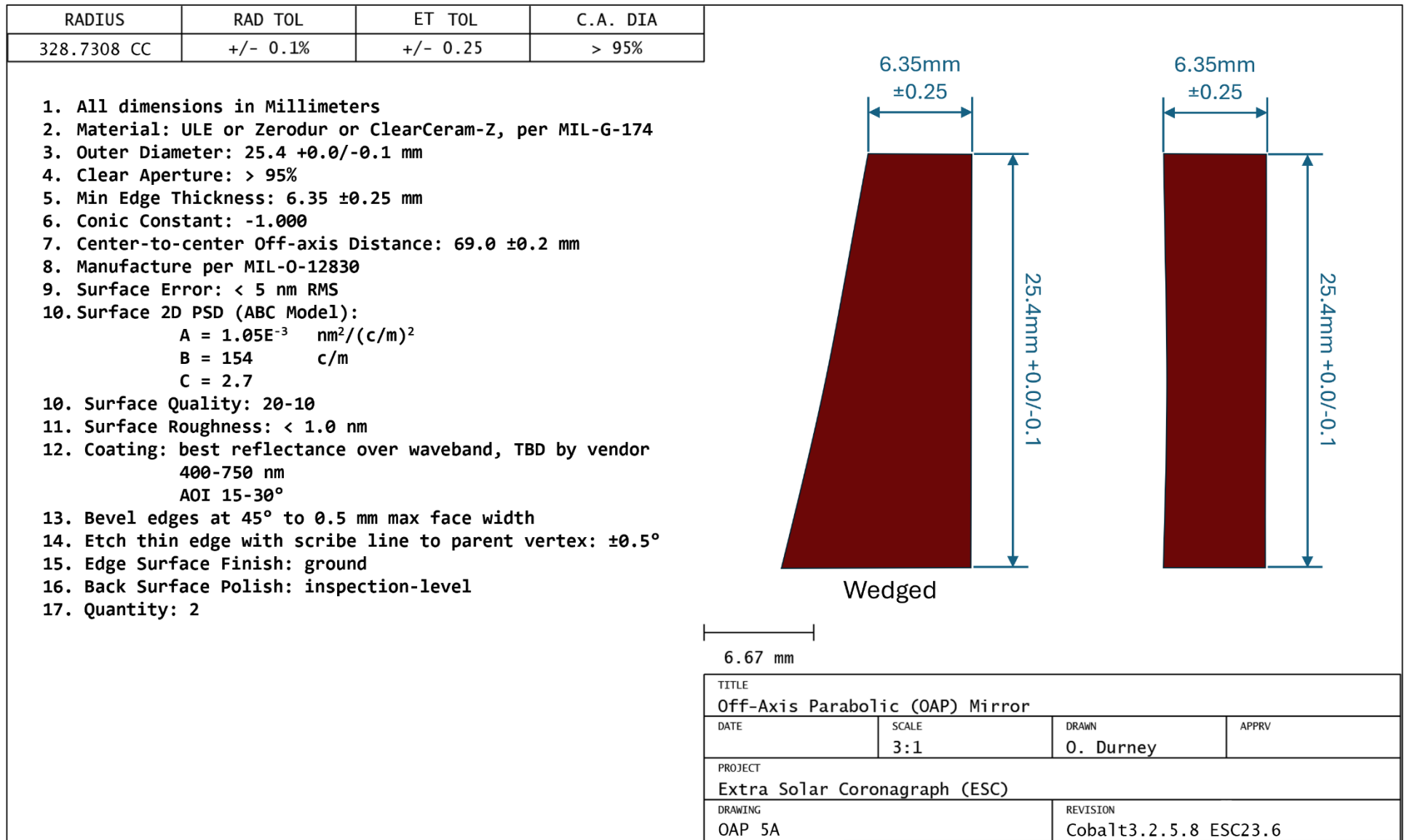


Figure 9: Off-axis parabolic mirror, OAP 5A drawing

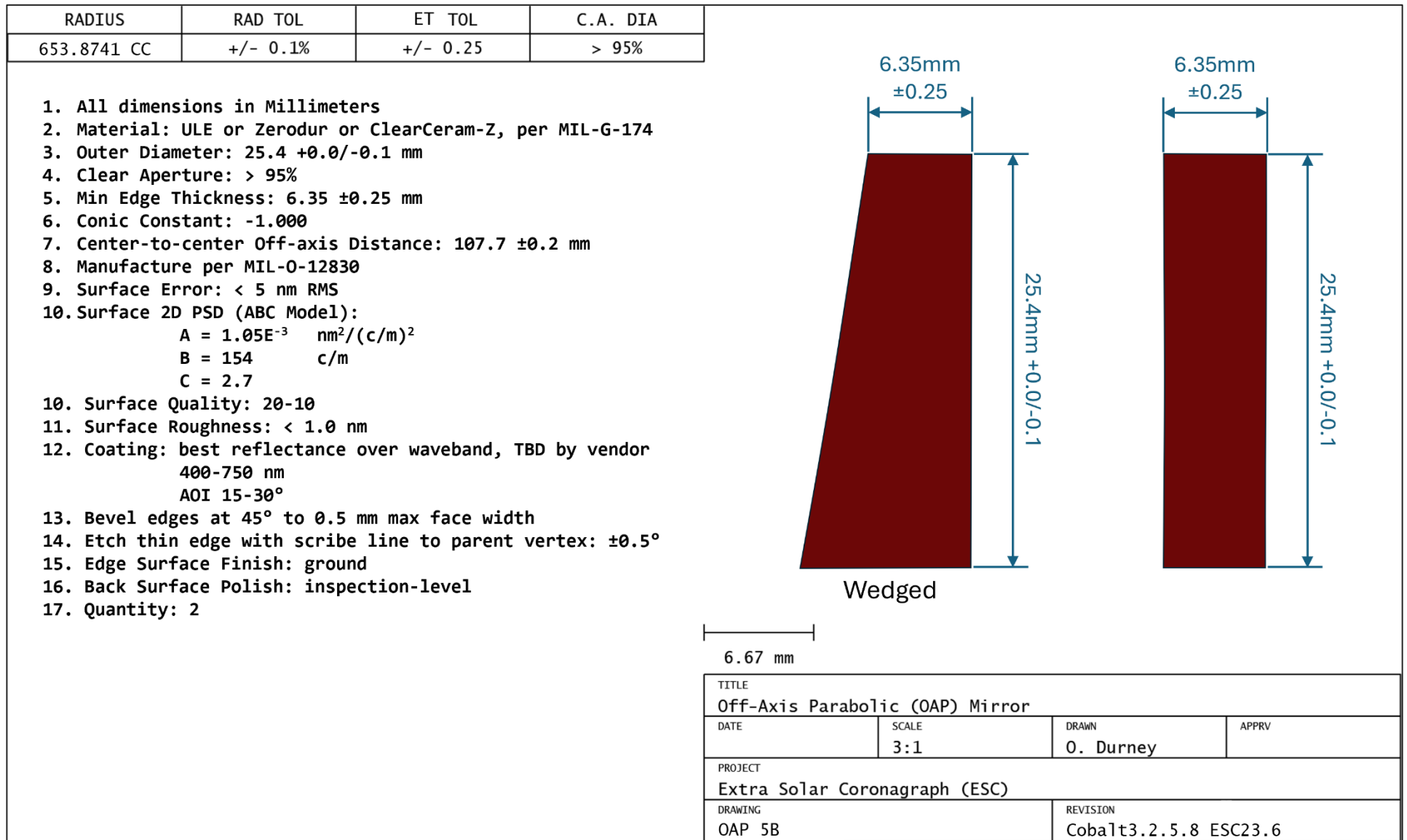


Figure 10: Off-axis parabolic mirror, OAP 5B drawing

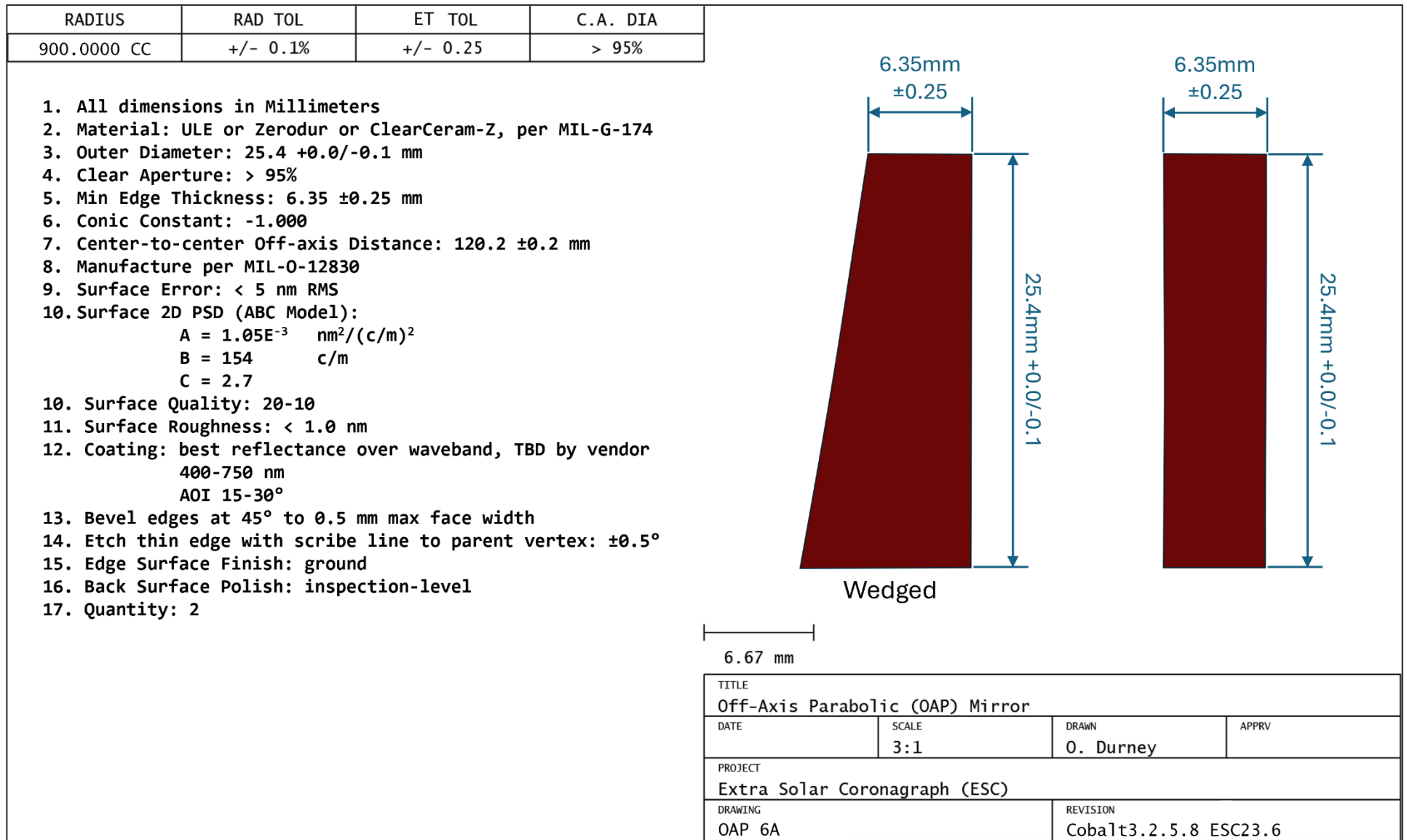


Figure 11: Off-axis parabolic mirror, OAP 6A drawing

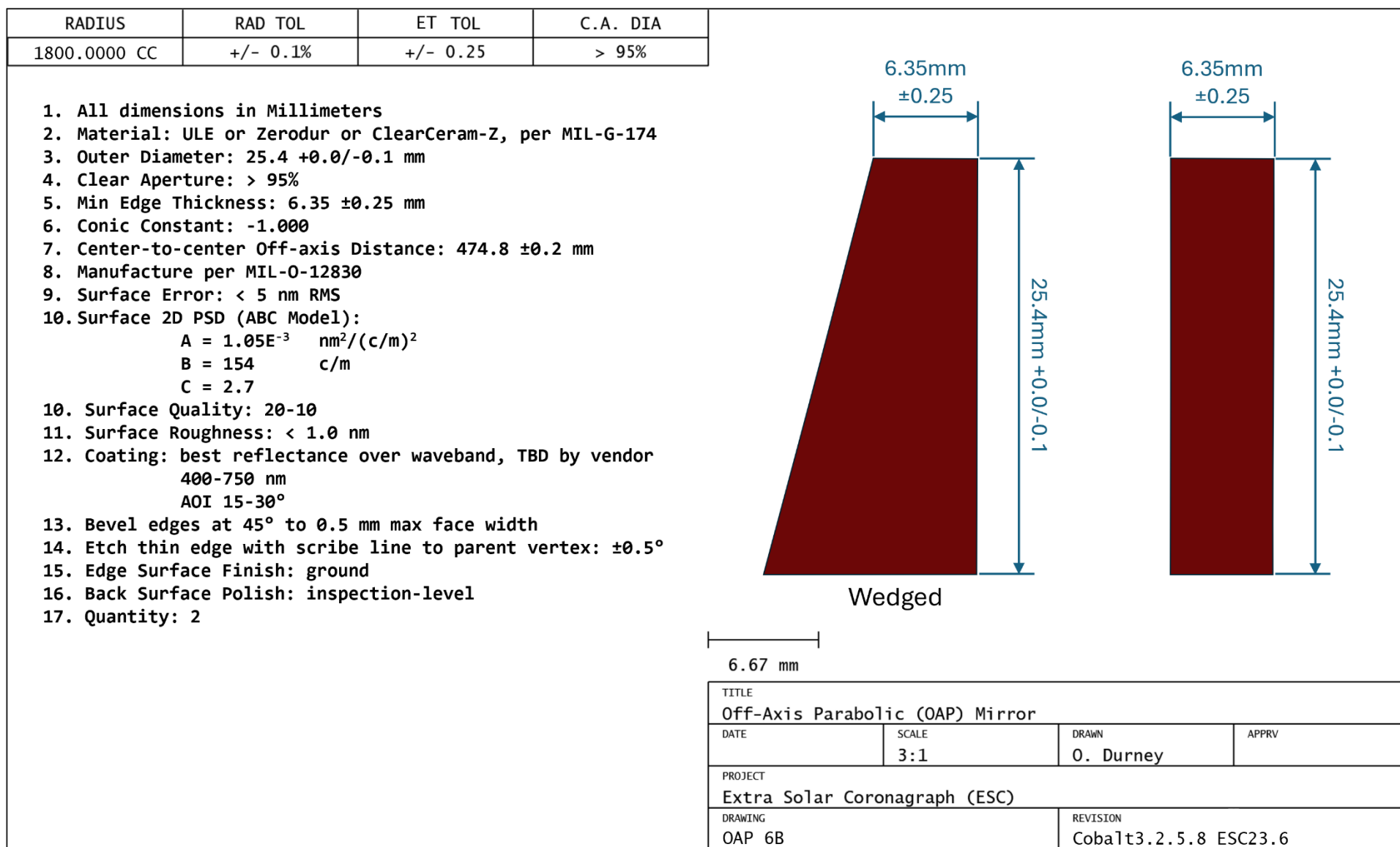


Figure 12: Off-axis parabolic mirror, OAP 6B drawing

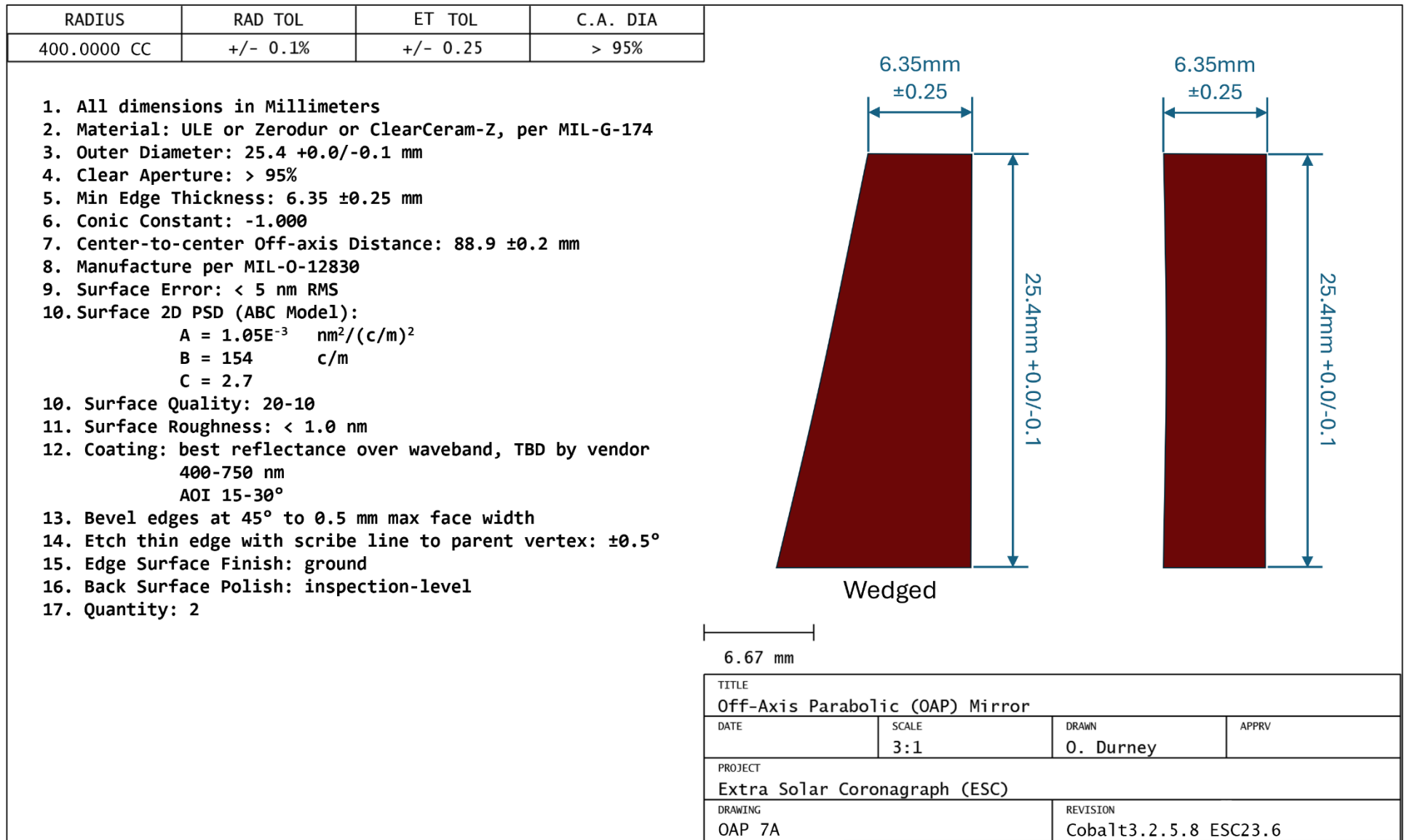


Figure 13: Off-axis parabolic mirror, OAP 7A drawing

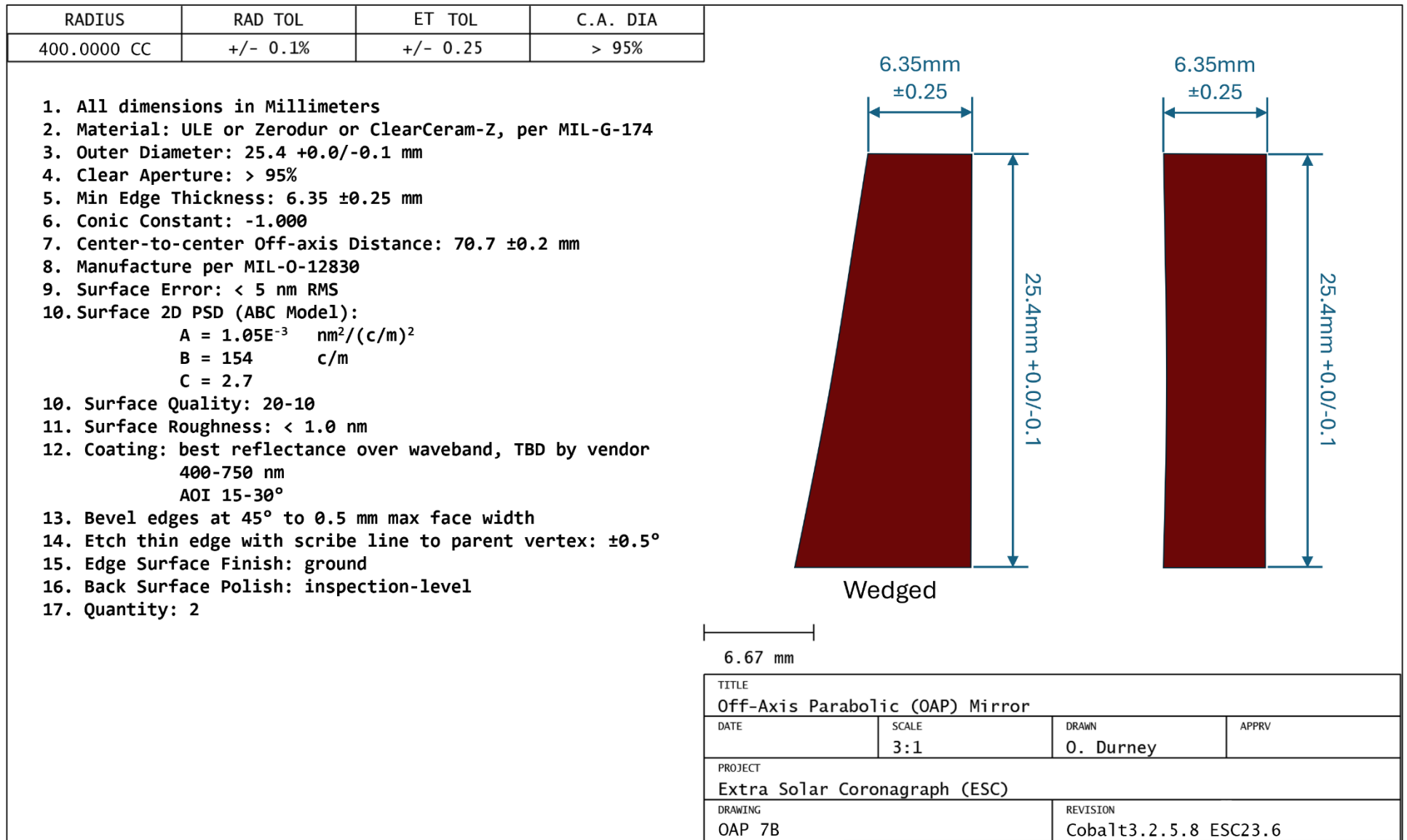


Figure 14: Off-axis parabolic mirror, OAP 7B drawing

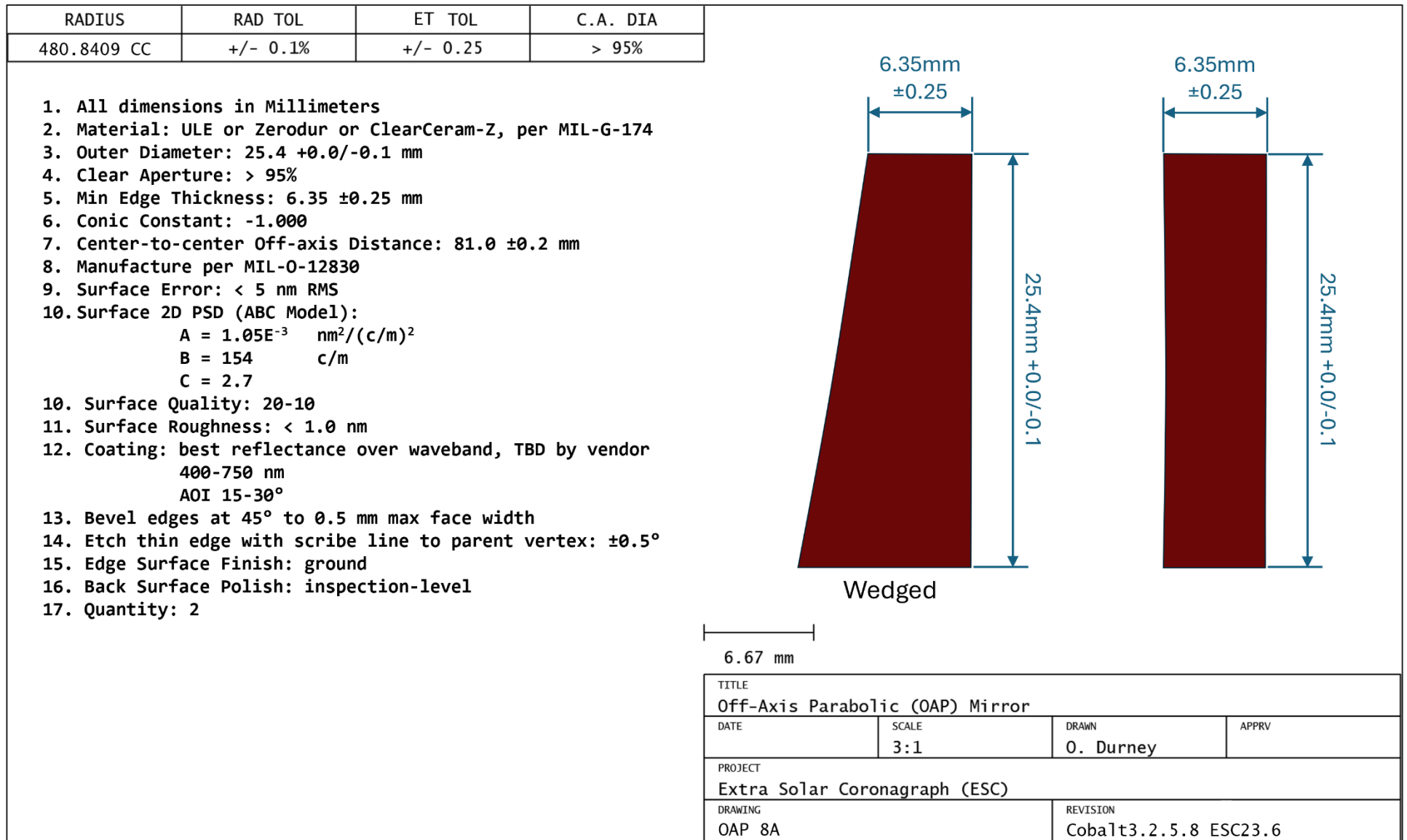


Figure 15: Off-axis parabolic mirror, OAP 8A drawing

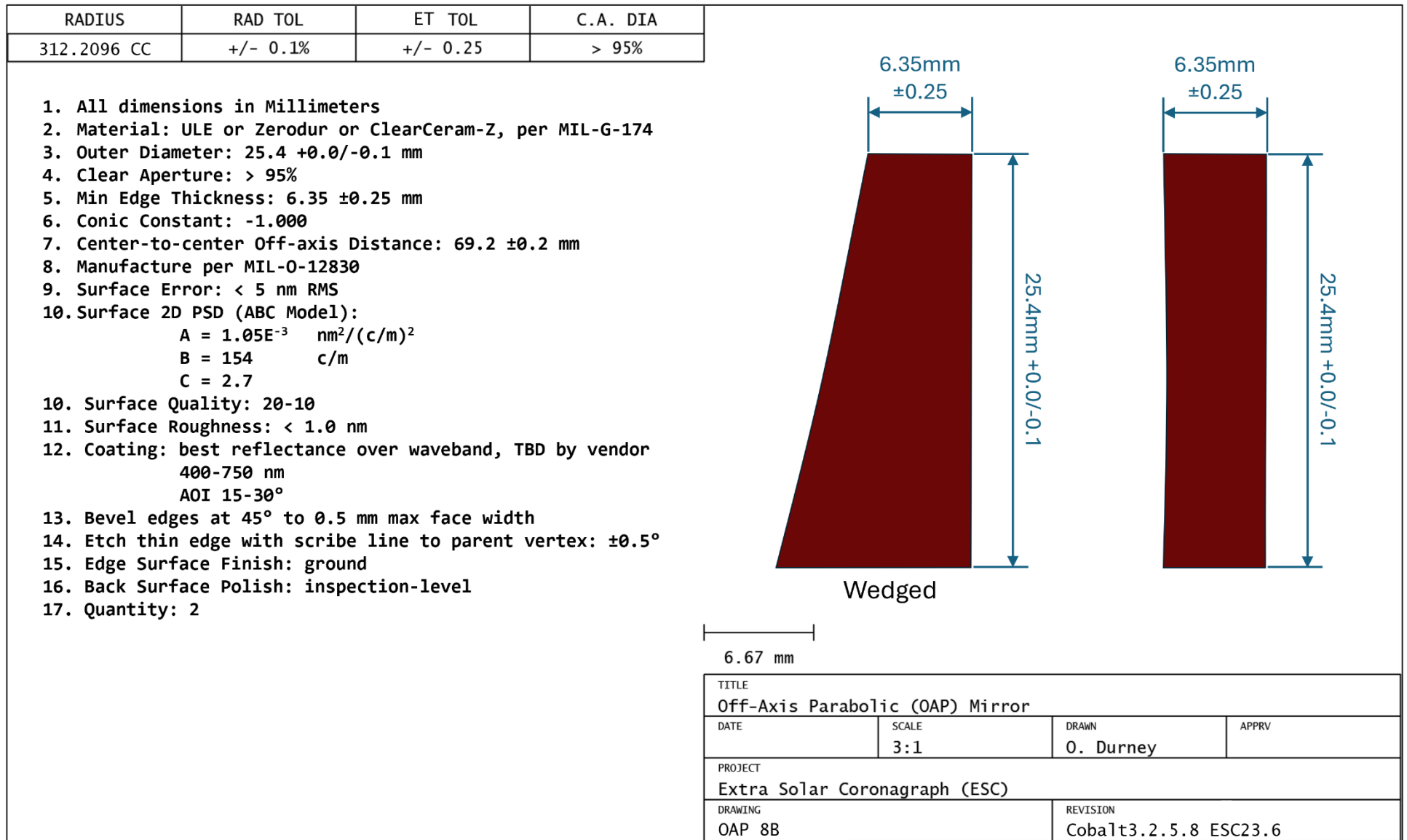


Figure 16: Off-axis parabolic mirror, OAP 8B drawing

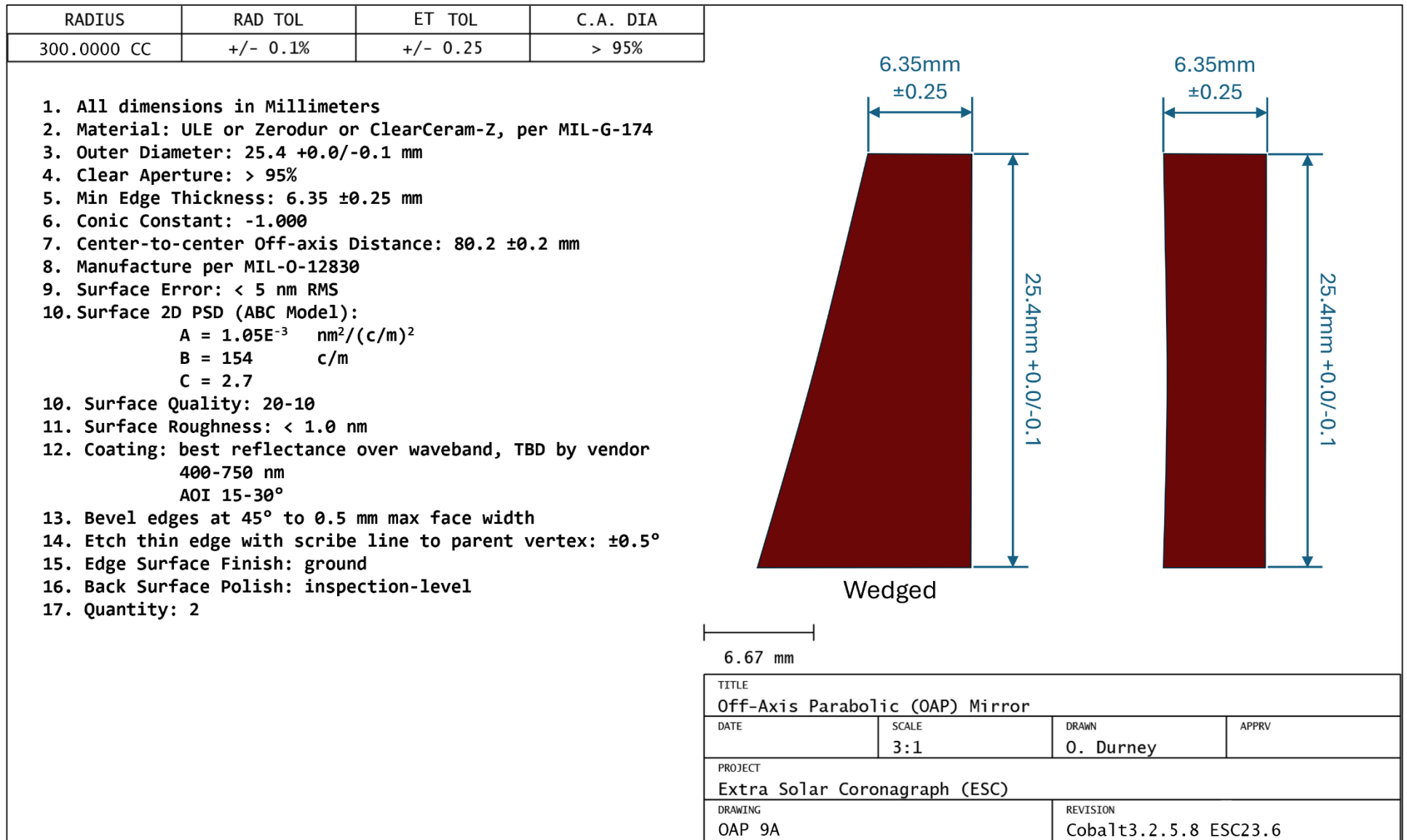


Figure 17: Off-axis parabolic mirror, OAP 9A drawing

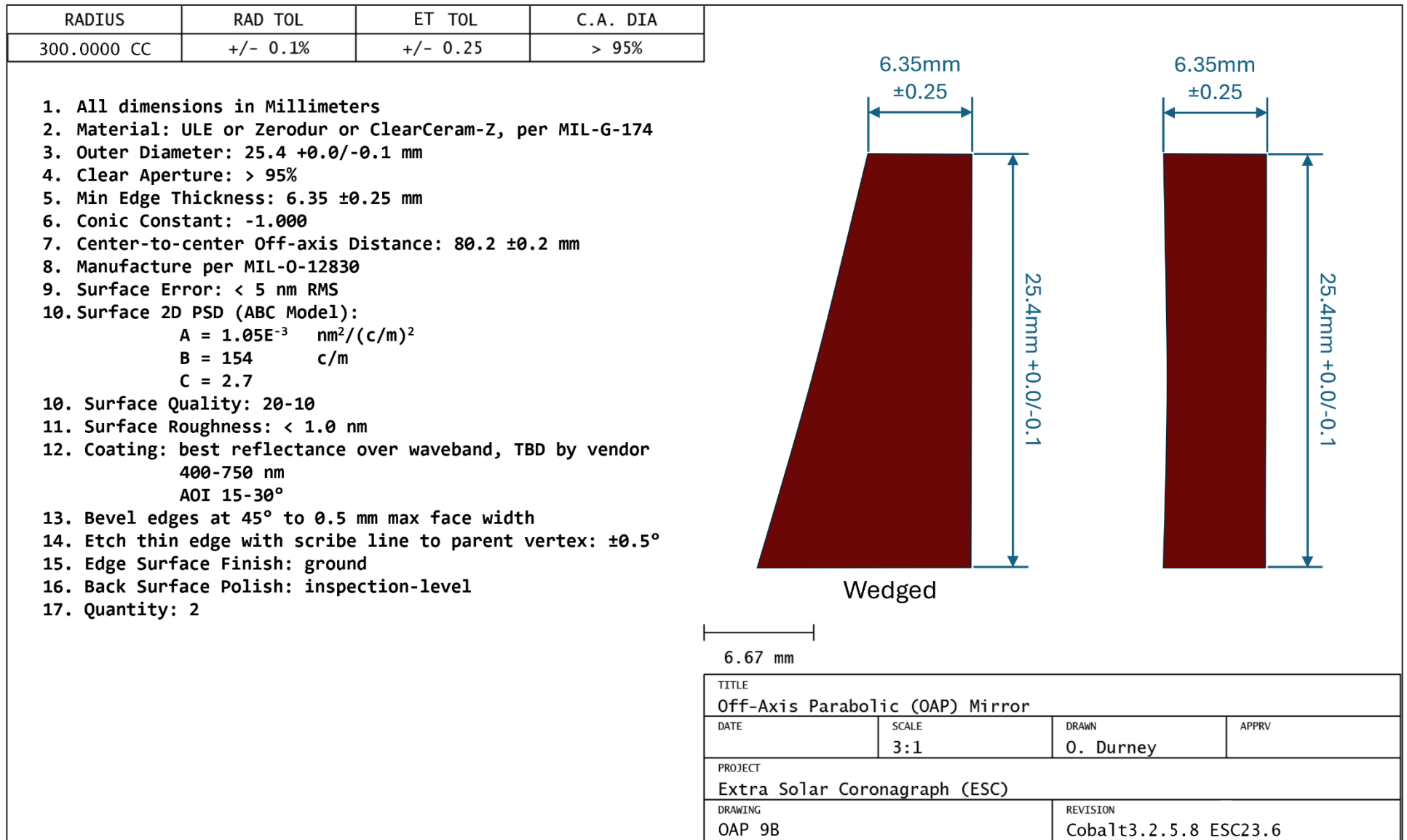


Figure 18: Off-axis parabolic mirror, OAP 9B drawing