School of Mechanical and Design Engineering

Coursework 2	Throttle Valve Component (Reverse Engineering & CAD/CAM)
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Contents

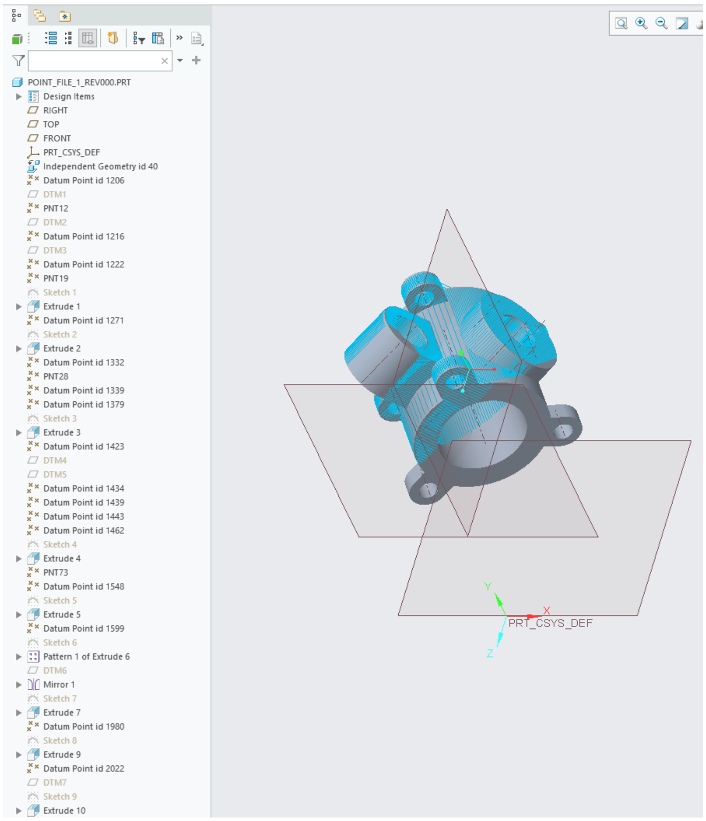
1.0 Introduction

This report presents the reverse engineering and product realisation of the Scan_3 throttle valve body in Creo. The work reconstructs the damaged scan as a parametric CAD model, verifies it against the point cloud, modifies it for aluminium die casting, develops the mould tooling, and defines the post casting CAM route for functional machining.

2.0 Reverse Engineering of the Point Cloud (±0.05%)

Key dimensions were extracted to define the component envelope and verification basis. Because scan uncertainty produced small non round dimensions, values were rationalised to rounded design intent dimensions while retaining the measured envelope for the tolerance calculation.

Figure 1: Datum framework and reconstruction setup used for reverse engineering of the point cloud in Creo



Key nominal dimensions were extracted from the reconstructed CAD model to define the overall component envelope and support subsequent verification. Due to scan noise and best fit reconstruction, extracted dimensions typically include small non-integer offsets; therefore, nominal values were rationalised to rounded “design intent” values consistent with how an original engineering drawing would normally be specified. For traceability, both the nominal measured values and the rounded design intent values are reported (Table 1). The nominal envelope dimension is retained to support the verification tolerance defined in Section 3.

Table 1: Extracted nominal dimensions and rounded design intent values

Feature / envelope dimension	Nominal measured value (mm)	Rounded design intent value (mm)
Height	400.004	400
Throttle outer diameter (OD)	399.984	400
Throttle inner diameter (ID)	259.997	260
Maximum overall width (envelope)	576.0358	576

3.0 Geometric Verification Against the Scan

The geometric accuracy of the reconstructed CAD model was verified against the imported point cloud using a deviation analysis in Creo. The acceptance criterion was defined as ±0.05% of the maximum overall part envelope dimension, L_{max} . For the reconstructed model, the maximum envelope dimension was measured as $L_{max} = 576.0358mm$ (overall width). The corresponding verification tolerance band was therefore:

Equation 1: Calculation of the ±0.05% scan verification tolerance band (±T) from the maximum part envelope dimension, L_{max}

$$T = 0.0005 \times L_{max} = 0.0005 \times 576.0358 = 0.288 \, mm$$

Hence, the model was considered acceptable where the deviation between CAD surfaces and the scan lay within ±0.288 mm. The deviation display was therefore configured to support interpretation against this criterion. Using five colour bands, the plotted bounds were set to ±0.864 mm (±3T) so that deviations within ±T are readily distinguishable from out of tolerance regions. The resulting deviation analysis returned a global maximum deviation of +0.088 mm and a global minimum deviation of -1.444 mm. The maximum deviation satisfies the acceptance criterion; however, the minimum deviation exceeds the acceptance criterion and was therefore examined locally using the displayed minimum marker to determine its spatial location before making an overall compliance statement

Table 2: Verification tolerance definition (±0.05% rule)

Parameter	Value
Maximum overall dimension, L_{max}	576.0358 mm
Tolerance fraction	0.05% = 0.0005
Acceptance tolerance, T = $0.0005L_{max}$	±0.288 mm
Deviation plot bounds	Upper = +0.864 mm; Lower = -0.864 mm
Display colours	5
Colour range legend values	+0.864 mm; +0.288 mm; -0.288 mm; -0.864 mm
Reported deviation results	Min = -1.444 mm; Max = +0.0875mm
Deviation analysis file	DEVIATION1.CDV

Figure 2: Deviation analysis result plot with colour legend visible

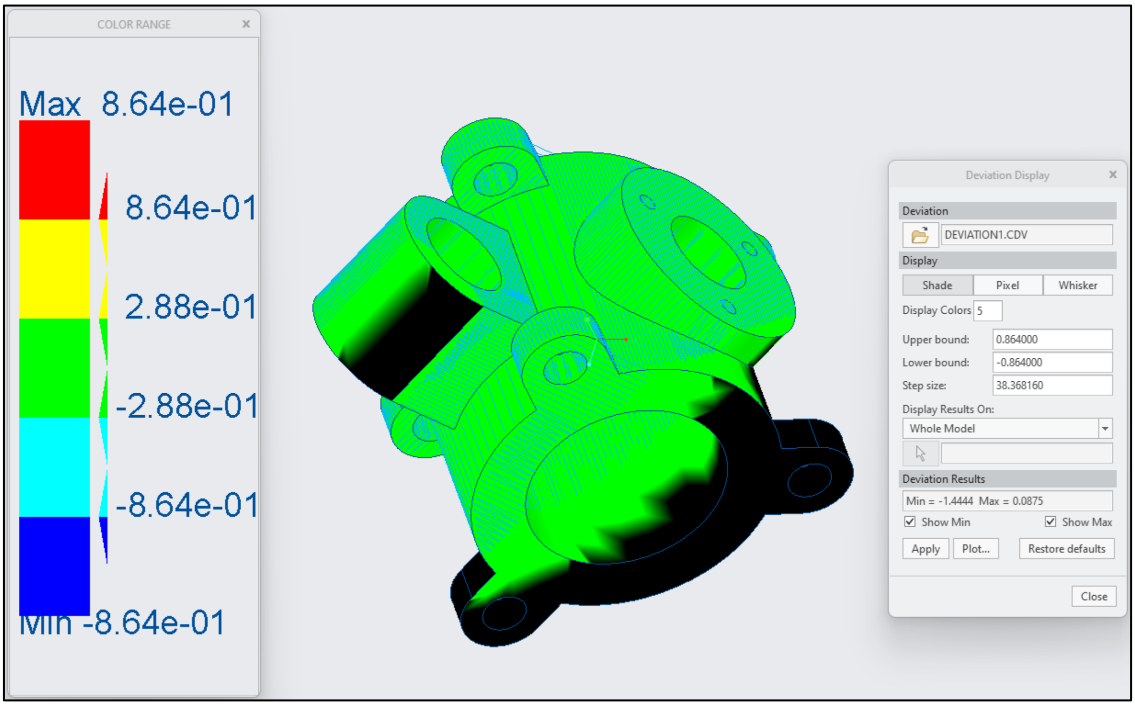
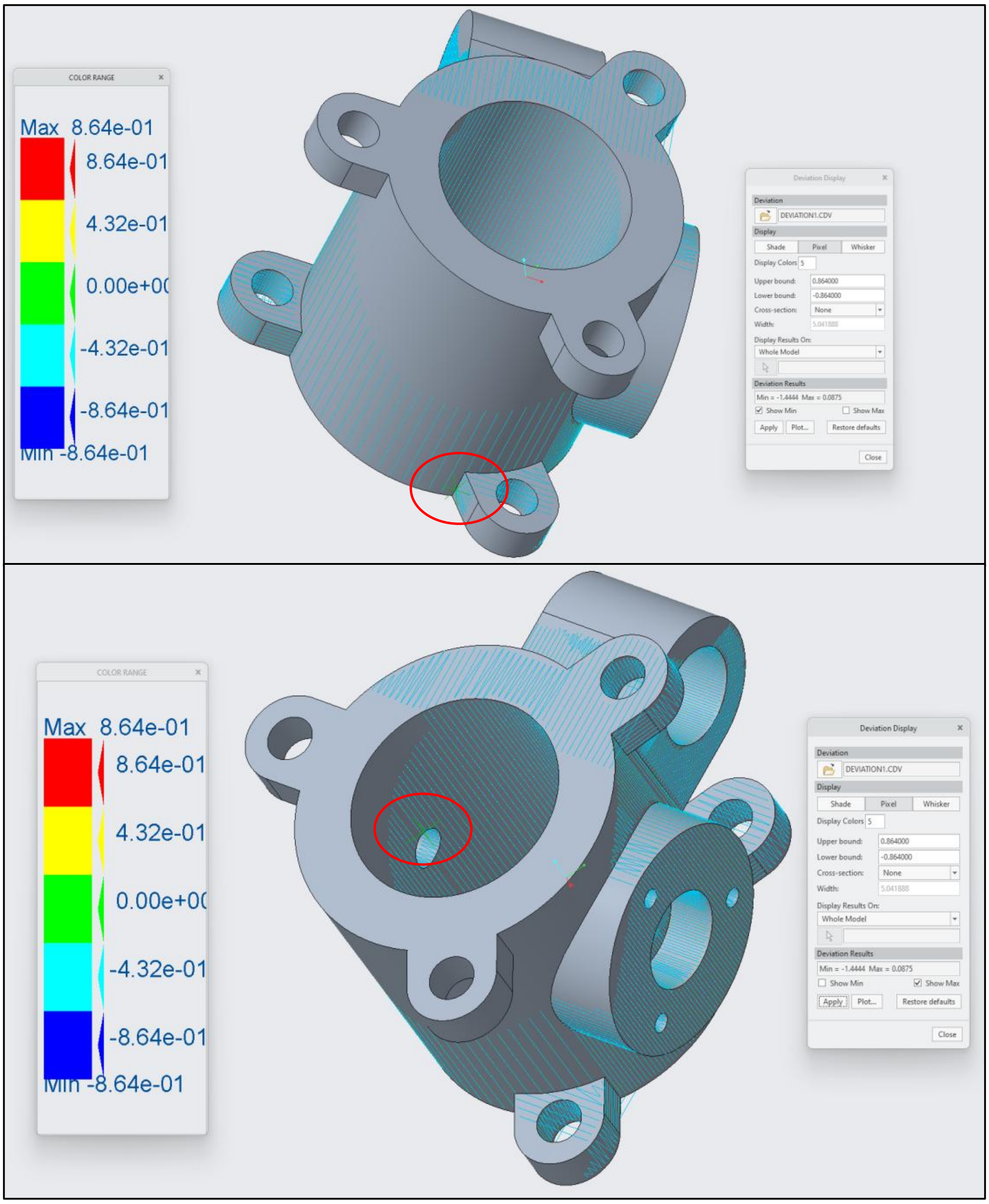


Figure 3: Pixel display views indicating the spatial locations of the reported global deviation extrema; (Top) global maximum deviation location; (Bottom) global minimum deviation location



The initial deviation analysis returned a local minimum deviation of -1.444 mm, outside the ±0.288 mm tolerance band. The deviation marker and pixel display views showed that this was confined to a local damage/non-design scan region, rather than the reconstructed functional surfaces. The remaining deviation field was within the defined tolerance band, with a maximum deviation of +0.0875 mm. The model was therefore accepted as a design intent reconstruction for subsequent die-casting and CAM development, with the isolated scan outlier recorded as excluded from the functional verification basis.

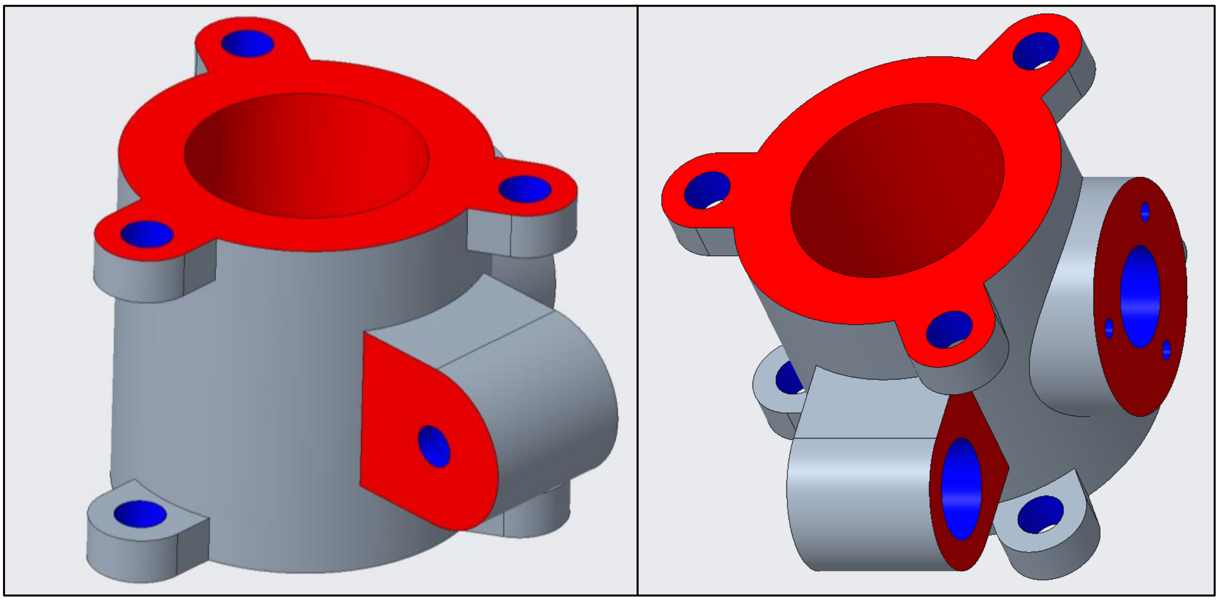
4.0 Design Modification for Die Casting and Machining

Functional features requiring dimensional accuracy were identified and assigned machining allowances to permit post casting finishing operations. The manufacturing classification of the modified geometry is summarised in Table 3 and shown in Figure 4.

Table 3: Manufacturing classification of features in the modified die casting model.

Feature	Classification	Justification	Key
Central bore	Machined	Functional cylindrical interface	Red
Top flange face	Machined	Mounting/sealing requirement	Red
Bottom flange face	Machined	Mounting/sealing/datum requirement	Red
Side flange face	Machined	Interface requirement	Red
Motor interface	Milled; drilled/bored	Functional fit; dimensional accuracy	Red; Blue
Mounting bolt holes	Drilled post cast	Positional accuracy	Blue
External body/lugs	As cast	No critical functional requirement	Grey

Figure 4: Manufacturing classification of the modified valve body before machining allowances were applied.



Mounting bolt holes were removed from the casting model and are intended to be drilled after casting to ensure positional accuracy. The motor housing interface requires both face machining and hole finishing operations and was therefore designated for milled and drilled/bored post-casting manufacture. External walls, bosses, and mounting lugs were retained as cast because no critical functional requirement is imposed on these surfaces.

Machining allowances followed BS EN ISO 8062-3:2023. The 576 mm envelope placed the component in the >400 to ≤630 mm band, RMAGC gives a 1.1 mm allowance, applied only to functional faces and bores (Appendix A, Table A1). Draft was checked against the machining stock added in the casting model. Applying draft directly to the stock added machined faces was found to reduce the remaining material below the finished nominal geometry, so this approach was not used. Instead, a 1° draft was applied only to the adjacent as-cast release walls, which allowed die withdrawal without compromising the stock required for later machining. Hole features were reviewed individually to decide whether they should remain in the die casting model aided by mandrel insertion.

Table 4: Hole retention decisions for the die-casting model

Hole/Feature	Cast?	Final method	Justification
Central throttle bore	Yes	Mandrel + machine	Major functional bore
Motor housing bore	Yes	Mandrel + machine	Large functional bore
Side shaft bore	Yes	Mandrel + machine	Simple through core
Flange mounting holes	No	Drill	Positional accuracy
Side flange bolt holes	No	Drill/profile	Small tolerance holes
Stepped shaft bore	No	Machine	Complex stepped form
Far shaft support hole	No	Drill	Small cross hole

5.0 Workpiece, Shrinkage and Mould Tooling Development

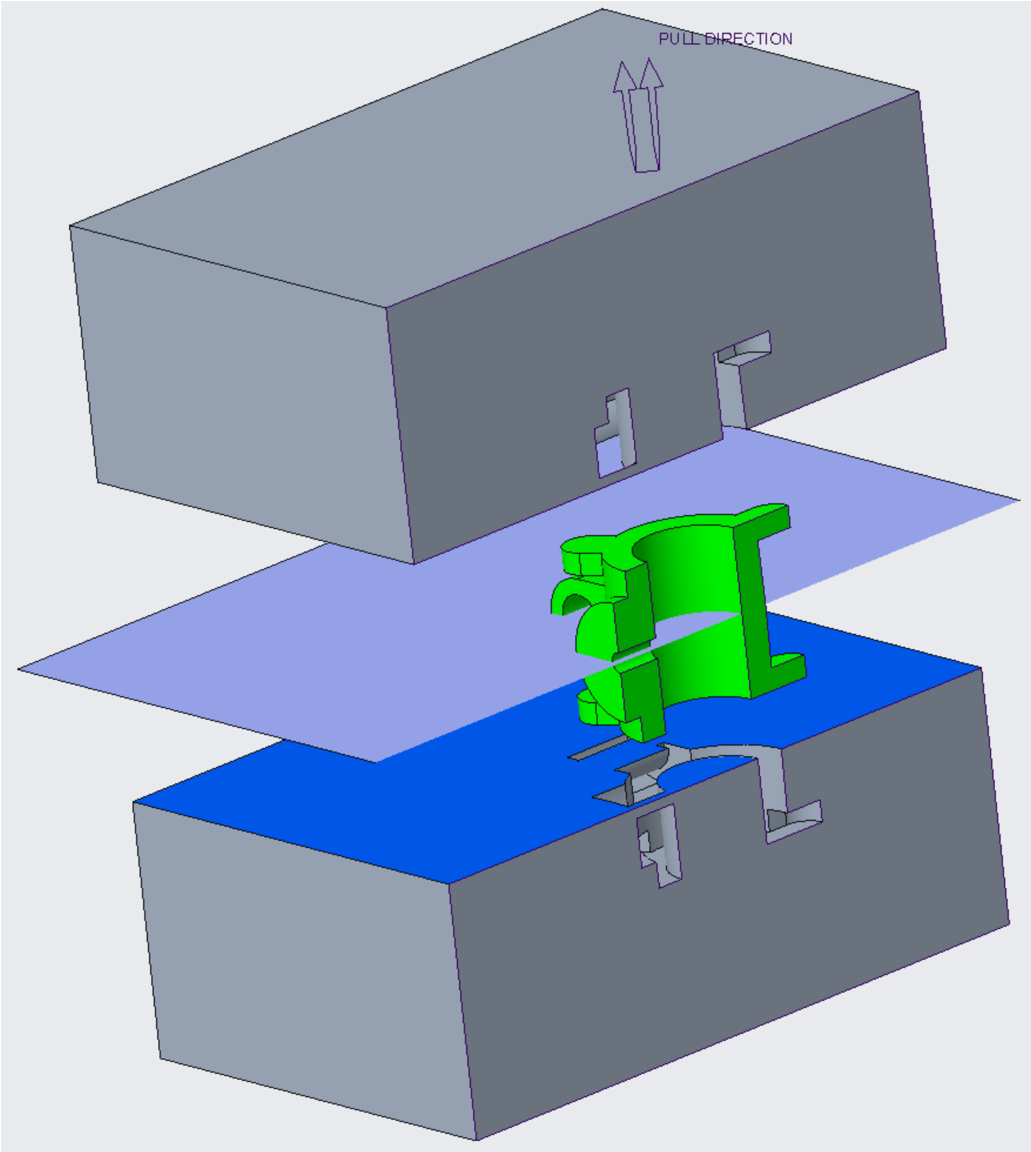
Table 5: Screening of candidate HPDC aluminium alloys for the selected throttle body casting

Material	Advantage for this project	Limitation for this project
A380	Direct match to the throttle body HPDC application (Nunes et al., 2017); supported by A380 die casting property and microstructure data (Obiekea et al., 2014)	Selected because it provides the strongest combined basis for application relevance, manufacturability, and process dependent mechanical performance.
EN AC-46000 / AISi9Cu3 (FE)	Relevant by analogy through HPDC water pump housing evidence (Kowalczyk et al., 2022)	Technically suitable, although its justification is less direct and its reported behaviour is more dependent on wall thickness and process conditions (Kowalczyk et al., 2022)
A360	Relevant to aluminium die casting in general, but the available case is a cover plate rather than a housing or throttle body component (Xu et al., 2025; NADCA, 2015)	Retained as a benchmark as the evidence does not closely represent the geometry or functional context of the selected component

A uniform linear shrinkage allowance of 0.6% was applied for the initial mould scaling, based on NADCA pattern shrinkage guidance for 380 die cast aluminium and adopted here as the closest available industry reference for the selected A380 alloy (NADCA, 2015). Since NADCA presents this value as generic die-casting guidance rather than a part specific constant, it was treated as an initial tooling assumption for cavity development. The reverse engineered body was converted from finished part geometry into a casting workpiece suitable for HPDC manufacture, so that the model used for mould development represented the 'as-cast' form rather than the final machined component. Critical features were retained for post cast machining, while any additional tooling elements were used only where required by the component geometry.

The mould workpiece was centred on the overall casting envelope rather than the throttle bore alone, because the asymmetric motor housing shifted the tooling envelope away from the main bore centreline; centring only on the bore would reduce die material on the asymmetric side of the component. The workpiece dimensions were defined as approximately three times the casting envelope and then rounded to practical values, giving a mould block of $1950 \times 1620 \times 1210\ mm$.The primary split was based on the central throttle bore axis as it is the dominant through feature and gives the simplest release direction for the main body. This established the primary mould concept, while release of retained cross axis features was left for draft based assessment rather than assumed at the split stage.

Figure 5: Workpiece, parting surface, and extracted



6.0 Draft Analysis of Mould Parts

Draft analysis used a 1° criterion with the central throttle axis as the pull direction. The main body released, but retained cross-axis bores did not; therefore, tapered sliders were added for the perpendicular features with Creo sliders. Tapers were applied to contact points with molten metal to support mandrel withdrawal, while the shank remained cylindrical to maintain sliding alignment. This is consistent with Huang et al. (2021), who state that features not aligned with the die opening direction require slider formation and that a demould slope is required to facilitate mould opening.

Table 6: Draft analysis response for retained bore features

Feature	Draft finding	Analytical value
Central throttle bore	Releases with primary pull	Formed by main die blocks
Motor housing and shaft bore	Cross axis non-release	Tapered sliders added

Figure 7: Refined mould concept with side mandrel and tapered slider at 1° (tapers circled in yellow)

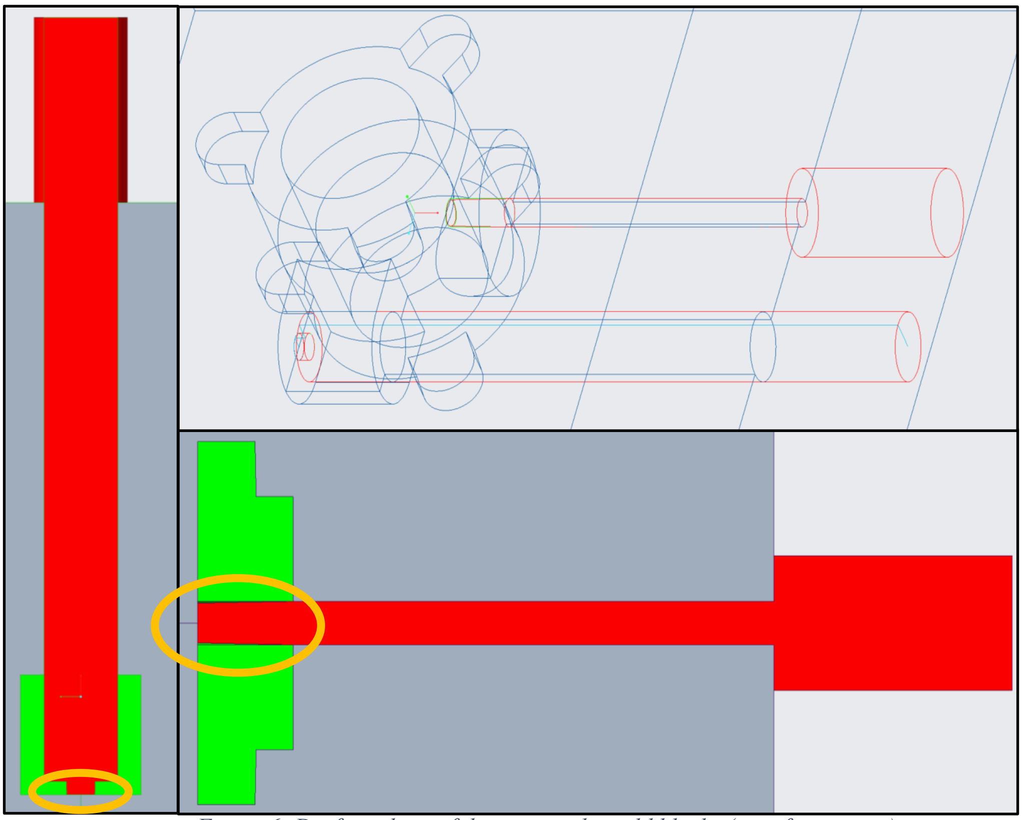
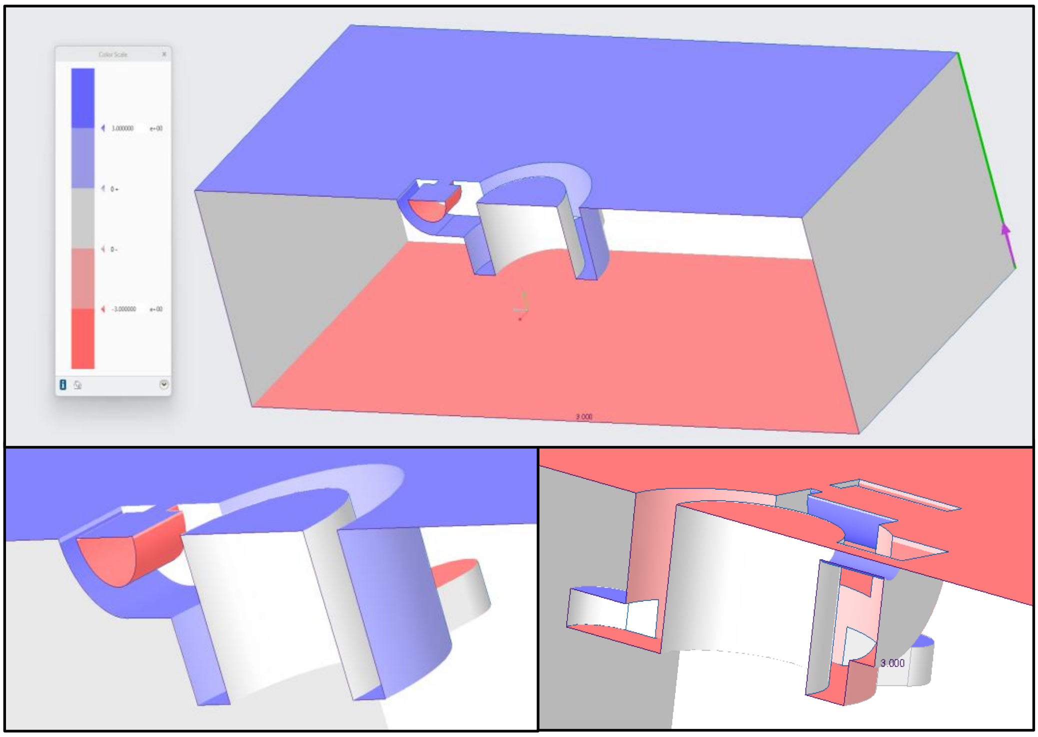


Figure 6: Draft analysis of the extracted mould blocks (wire frame view)



7.0 Test Shot and Material Estimation (1000 Units)

A Creo test shot was generated from the completed mould cavity to confirm the final moulded volume before material estimation. The part was assigned the custom A380 material definition before mass properties were evaluated (NADCA, 2015). The resulting volume and mass were then used to estimate the net material requirement for 1000 castings.

Table 7: CAD derived test shot mass estimate for 1000 A380 castings

Parameter	Value	Unit	Evidence / assumption
Test shot model	Valve_Test_Shot_Rev000	N/A	Generated from mould cavity
Assigned material	Alumium_A380_F	N/A	Section 5
Density	2.76×10^{-9}	tonne/mm^3	From A380.0-F datasheet
Test shot volume	3.99×10^{7}	mm^3	Creo Mass Properties
Mass per test shot	1.11×10^{-1}	tonne	Creo Mass Properties
Mass per test shot	110.11	Kg	Converted from tonnes
Quantity	1000	Units	Coursework requirement
Total net material	110.11	Tonnes	Equation 2
Excluded geometry	Runner, biscuit, overflow	N/A	Excluded because not modelled

Equation 2

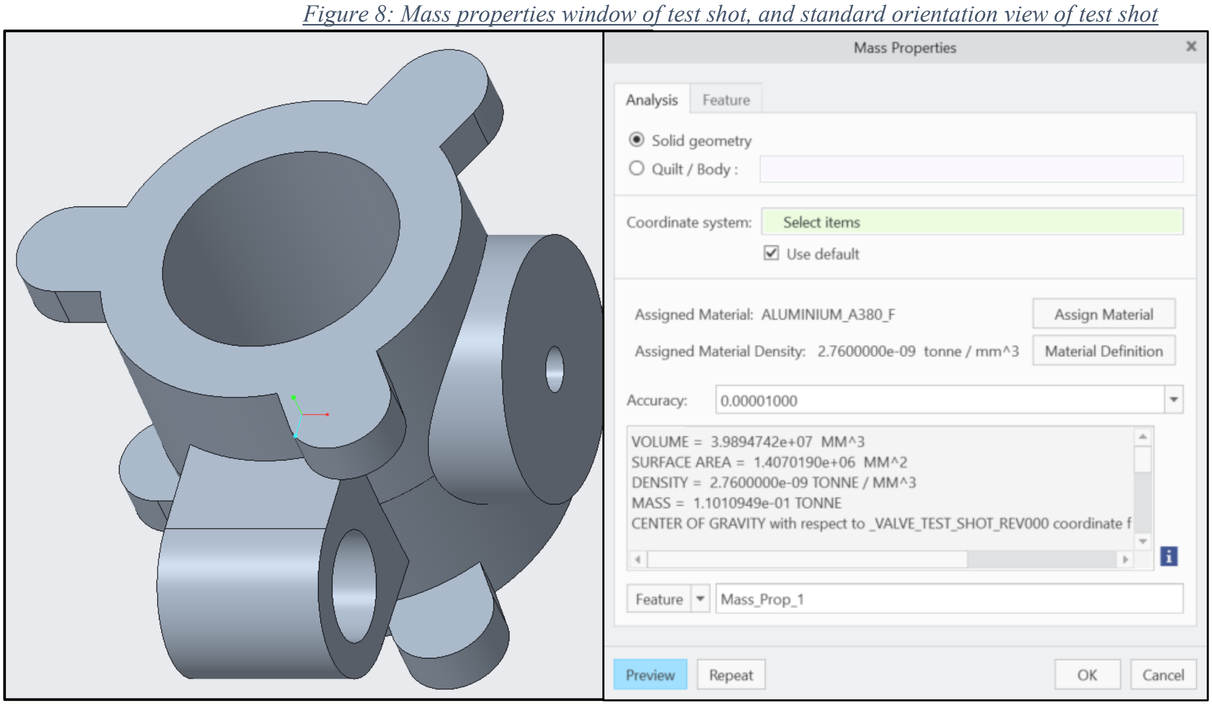
$$m_{1000} = m_{shot} \times 1000$$

$$\Rightarrow m_{1000} = 0.11010949 \times 1000$$

$$\Rightarrow m_{1000} = 110.10949 \approx 110.11\ tonnes$$

This is the net casting mass only; runner, biscuit, overflow and gating losses were excluded because they were not modelled.

Figure 8: Mass properties window of test shot, and standard orientation view of test shot



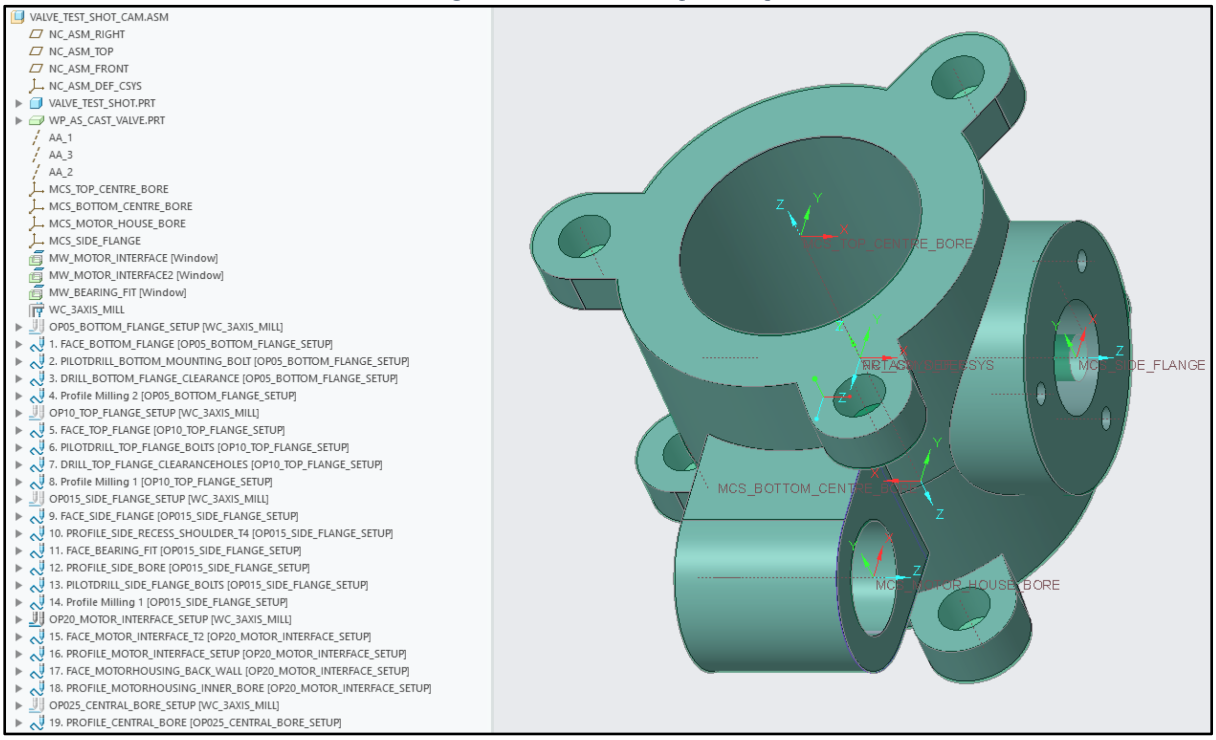
8.0 Process Plan and Manufacturing Sequences

The CAM plan implemented the feature decisions defined by Section 4.0 by using the die-cast model as the machining reference and organising the setup around the stock definition, machine coordinate system and operation setup and verified toolpath sequences. The sequence was ordered to establish stable machined datums before finishing dependent bores and drilled feature, so the plan remained traceable from casting geometry to manufacturing output rather than treating the toolpaths as isolated features (Dotchev & Popov, 2021). Process control remains a production limitation because A380 HPDC properties vary with injection speed, boost pressure and wall thickness response; therefore, physical trials or mould flow simulation would still be required before production release (Li et al., 2023).

Table 8: CAM sequence plan for post casting machining

Order	Setup	Functional machining
1	OP05 Bottom flange	Established the primary machined datum for later setup control
2	OP10 Top flange	Controls opposing face relationship after the base datum is established
3	OP15 Side flange	Completes the lateral interface before side feature finishing
4	OP20 Motor interface	Establishes the local datum for the motor housing bore
5	OP25 Central bore	Finished in the same setup as above to avoid unnecessary setup

Figure 9: Final CAM setup and sequence order



9.0 Cutting Parameters and Feed/Speed Calculations

Cutting parameters were calculated before CAM verification because simulated sequence time in Creo depends on the spindle speed and feed rate assigned to each machining operation. This prevents the machining time estimate from being based on arbitrary CAM defaults and keeps later optimisation traceable to the selected tools and material (Dotchev & Popov, 2021).

Table 9: Preliminary McMaster-Carr tooling selection for post-cast aluminium machining (McMaster-Carr, N.D)

ID	Part No.	Tool Geometry	Operations	Justification
T01	8826A52	Ø76.2 face mill, 10 teeth	Face milling	Fewer passes on broad faces
T02	8945A42	Ø16 square end mill, 3 teeth	Restricted access profile milling	Smaller diameter allows greater access
T03	8382N16	Ø19.05 square end mill, 4 teeth	Central bore profile	Long reach bore access
T04	8945A39	Ø12 square end mill, 3 teeth	Profiles, Ø24 holes	Circular interpolation
T05	2979N34	Ø12 twist drill, 135 ° point angle	Pilot holes	Positional control
T06	3070A108	Ø50 HSS drill, 118° point angle	Large clearance holes	Diameter compatible only

For milling sequences, spindle speed *(N)* in *rev/min*, and feed rate *(F)* in *mm/min* were calculated using Equations 3 and 4:

Equation 3: Milling spindle speed

$$N = \frac{1000V_c}{\pi D}$$

Equation 4: Milling feed rate

$$F = f_z \times z \times N$$

For drilling sequences, feed rate was calculated using Equation 5:

Equation 5: Drilling feed rate

$$F = f_r \times N$$

where V_c is cutting speed *(m/min)*, D is cutter diameter *(mm)*, f_z is feed per tooth *(mm/tooth)*, f_r is feed per revolution *(mm/rev)*, and *z* is the number of teeth or flutes.

Table 10: Feed and speed calculation summary for Creo CAM inputs

ID	**Parameter basis**				**Calculation used in Creo**	
T01	$D = 76.2$	$z = 10$	$V_c = 150$	$f_z = 0.04$	$N = 626$	$F = 250$
T02	$D = 16$	$z = 3$	$V_c = 150$	$f_z = 0.04$	$N = 2985$	$F = 358$
T03	$D = 19.05$	$z = 4$	$V_c = 150$	$f_z = 0.04$	$N = 2507$	$F = 401$
T04	$D = 12$	$z = 3$	$V_c = 150$	$f_z = 0.04$	$N = 3978$	$F = 477$
T05	$D = 12$	*N/A*	$V_c = 60$	$f_r = 0.12$	$N = 1592$	$F = 191$
T06	$D = 50$	*N/A*	$V_c = 60$	$f_r = 0.12$	$N = 318$	$F = 57$

The cutting strategy distinguished between allowance removal and finishing. Where the 1.1 mm machining allowance was removed, larger engagement values were permitted, whereas finishing and functional profile passes used a halved step depth of 0.55mm to improve dimensional control. This was especially important for surfaces defined as functional post cast geometry rather than cosmetic 'as cast' regions.

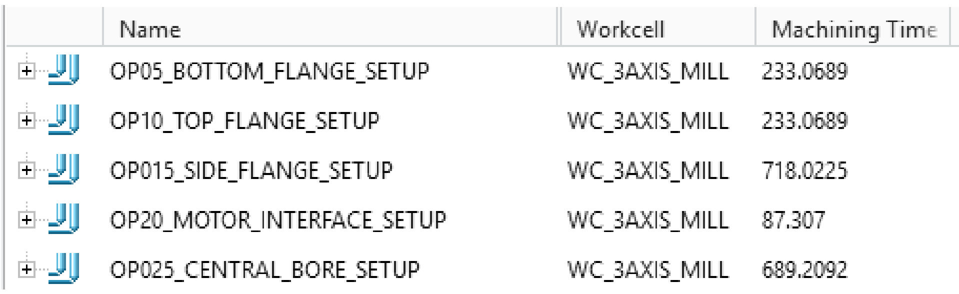
10.0 Machining Time Estimation, Optimisation and Post Processing

Machining time optimisation was based on the longest simulated sequences, rather than changing all operations equally. This approach follows the Creo CAM workflow described by Dotchev and Popov (2021), where sequence-time data is reviewed and the largest time contributors are targeted through realistic parameter or strategy changes.

Table 11: Interpreted machining time summary

Setup	**Time (min)**	**Time Driver**	**Driver time (min)**
OP05 Bottom flange	233.07	Profile milling	183.04
OP10 Top flange	233.07	Profile milling	183.04
OP15 Side flange	718.02	Profile milling	634.90
OP20 Motor interface	87.31	Motor interface profile	38.68
OP25 Central bore	689.21	Central Bore profile	689.21
Total baseline	**1960.58**	**N/A**	**32.68 h**

Figure 11: Creo Process Manager machining time output for the baseline CAM sequence set



Name	Workcell	Machining Time
OP05_BOTTOM_FLANGE_SETUP	WC_3AXIS_MILL	233.0689
OP10_TOP_FLANGE_SETUP	WC_3AXIS_MILL	233.0689
OP015_SIDE_FLANGE_SETUP	WC_3AXIS_MILL	718.0225
OP20_MOTOR_INTERFACE_SETUP	WC_3AXIS_MILL	87.307
OP025_CENTRAL_BORE_SETUP	WC_3AXIS_MILL	689.2092

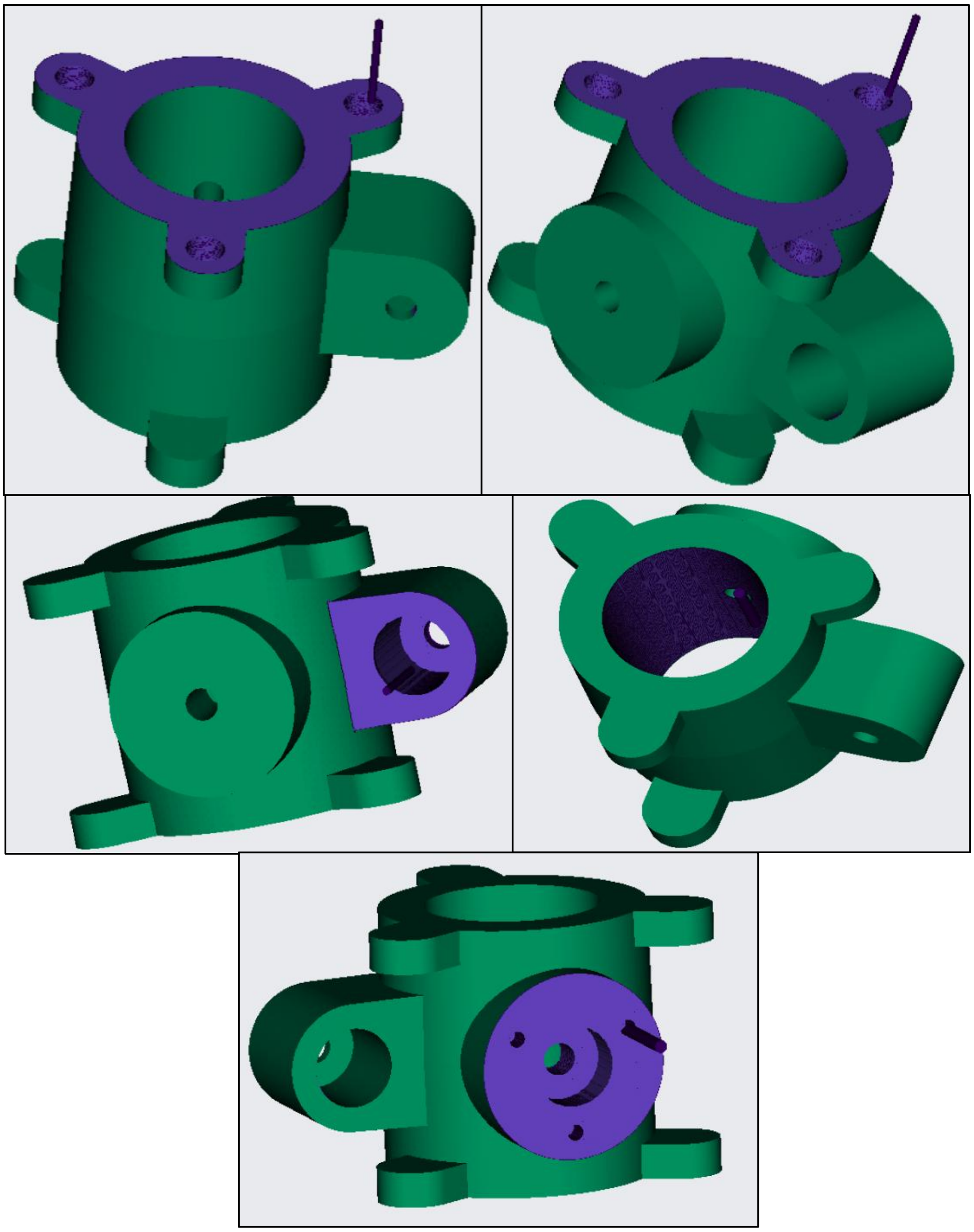
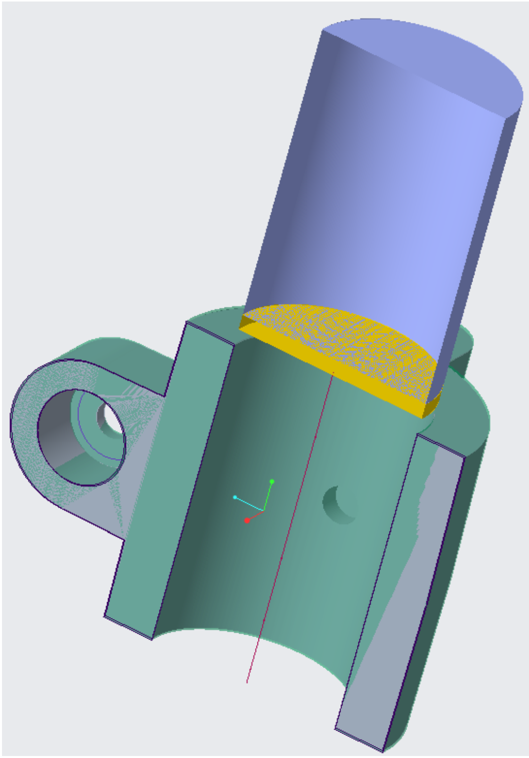


Table 12: CAM optimisation summary; dimensions in mm (NIKKEN, 2023)

Step	Target	Before	After	Before	After	Saving	Reduction	Decision
1	OP15 side holes	1 path, 3 holes	3 single hole paths	634.90	39.73	595.16	93.74%	Accepted
2	OP25 central bore	T03 profile milling	T07 RAC/RAK boring	639.21	6.41	682.79	99.07%	Accepted
Final	CAM total	Baseline	Steps 1+2	1960.68	682.72	1277.96	65.18%	Accepted

The optimised sequence set was output as an NCL file, verified using final Play Path/NC Check evidence, and post processed using a FANUC compatible post processor to generate the final “. tap” CNC programme. Child CNC files are retained within the directory as reproducible CAM evidence.

Figure 12: Play Path verification of the T07 RAC/RAK boring optimisation for the OP25 central bore



Conclusions

This work demonstrated that the main value of an integrated CAD/CAM system is the traceability it provides from scan reconstruction, geometric verification, and die-casting modification through to mould development, machining simulation, and CNC output. Creo allowed design decisions made during reverse engineering and casting preparation to remain linked to the later CAM strategy, so functional features could be identified, machined selectively and optimised using simulated machining time. The main limitation is that his remains a digital validation: A380 casting performance, mould filling behaviour and the custom boring strategy would still require supplier confirmation, mould flow simulation or physical trial before production release.

Appendix

Appendix A – Machining Allowance Application for Die Casting Model

Table 13: Comparison of Finished Nominal Dimensions and Die Casting Model Dimensions Including Machining Allowances (dimensions in mm)

Feature	Nominal	Allowance	Cast model	Finish
Central bore	Ø260.0	-2.2 dia.	Ø257.8	Machined
Top & bottom faces	400.0	1.1 per face; +2.2 overall	402.2	Machined
Side flange	240.0	+1.1 one side	241.1	Machined
Motor interface face	90.0 from centre	+1.1 one side	91.1	Milled
Motor large bore	Ø120.0	-2.2 dia.	Ø117.8	Drilled/bored
Motor small bore	Ø48.0	-2.2 dia.	Ø45.8	Drilled/bored

Table 12 — Required machining allowance

Dimensions in millimetres

Largest overall dimension		Machining allowance for required machining allowance grade (RMAG)									
		RMAG A	RMAG B	RMAG C	RMAG D	RMAG E	RMAG F	RMAG G	RMAG H	RMAG J	RMAG K
—	≤ 40	0,1	0,1	0,2	0,3	0,4	0,5	0,5	0,7	1	2
> 40	≤ 63	0,1	0,2	0,3	0,3	0,4	0,5	0,7	1	1,4	3
> 63	≤ 100	0,2	0,3	0,4	0,5	0,7	1	1,4	2	2,8	4
> 100	≤ 160	0,3	0,4	0,5	0,8	1,1	1,5	2,2	3	4	6
> 160	≤ 250	0,3	0,5	0,7	1	1,4	2	2,8	4	5,5	8
> 250	≤ 400	0,4	0,7	0,9	1,3	1,8	2,5	3,5	5	7	10
> 400	≤ 630	0,5	0,8	1,1	1,5	2,2	3	4	6	9	12
> 630	≤ 1 000	0,6	0,9	1,2	1,8	2,5	3,5	5	7	10	14
> 1 000	≤ 1 600	0,7	1	1,4	2	2,8	4	5,5	8	11	16
> 1 600	≤ 2 500	0,8	1,1	1,6	2,2	3,2	4,5	6	9	13	18
> 2 500	≤ 4 000	0,9	1,3	1,8	2,5	3,5	5	7	10	14	20
> 4 000	≤ 6 300	1	1,4	2	2,8	4	5,5	8	11	16	22
> 6 300	≤ 10 000	1,1	1,5	2,2	3	4,5	6	9	12	17	24
Grades A and B shall only be applied in special cases, for example with series production in which the pattern equipment, the casting procedure and the machining procedure with regard to clamping surfaces and datum surfaces or targets have been agreed between the customer and the foundry.											

Table of Figures

List of Tables

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