



POLITECNICO DI MILANO

SCUOLA DEL DESIGN

CORSO DI LAUREA MAGISTRALE IN

DESIGN & ENGINEERING

PROGETTO E INGEGNERIZZAZIONE DEL PRODOTTO INDUSTRIALE

**Design, Validation and Production of an
Edge Device Chassis for Machine Tools**

Engineering Validation of a Machine-Integrated
Enclosure Architecture

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Academic Year 2025–2026

Abstract

This thesis presents a validation-oriented engineering investigation of a machine-integrated industrial edge device enclosure intended for deployment in CNC machining environments. In such contexts, conventional assumptions of isolation, benign loading, and cabinet-level protection are insufficient, while exhaustive numerical optimisation is neither practical nor representative of industrial development practice.

The investigation deliberately treats enclosure architecture, material system, manufacturing strategy, installation logic, and electronic configuration as fixed boundary conditions. Engineering analysis is therefore positioned not as a tool for redesign, but as a structured method for assessing mechanical plausibility, airflow coherence, and configuration-level robustness under representative operating assumptions.

Mechanical simulation is employed to examine load transfer behaviour, deformation trends, panel stiffness, and modal characteristics under installation and handling scenarios. Airflow modelling is used to verify ventilation organisation and pressure distribution under both representative and elevated thermal loading. Risk and reliability are assessed through structured interface-level reasoning informed by DFMEA principles and supported by assembly and maintainability verification.

The contribution of this thesis lies in formalising a pragmatic, industry-aligned validation methodology for machine-integrated hardware. By combining disciplined boundary definition with targeted simulation and engineering judgement, the work establishes structural and thermal coherence within a constraint-driven artefact and defines a technically specified reference configuration suitable for industrial realisation.

Abstract (Italiano)

Questa tesi presenta un'indagine ingegneristica orientata alla validazione di un involucro per dispositivo edge industriale integrato su macchina, destinato all'impiego in ambienti di lavorazione CNC. In tali contesti, le convenzionali ipotesi di isolamento, carichi trascurabili e protezione a livello di quadro elettrico risultano insufficienti, mentre un'ottimizzazione numerica esaustiva non è né pratica né rappresentativa delle reali dinamiche dello sviluppo industriale.

L'indagine considera deliberatamente l'architettura dell'involucro, il sistema materiale, la strategia produttiva, la logica di installazione e la configurazione elettronica come condizioni al contorno fissate. L'analisi ingegneristica non è quindi impostata come strumento di riprogettazione, ma come metodo strutturato per valutare la plausibilità meccanica, la coerenza del flusso d'aria e la robustezza a livello di configurazione in condizioni operative rappresentative.

La simulazione meccanica è impiegata per analizzare il trasferimento dei carichi, le tendenze di deformazione, la rigidità dei pannelli e le caratteristiche modali in scenari di installazione e movimentazione. La modellazione del flusso d'aria è utilizzata per verificare l'organizzazione della ventilazione e la distribuzione delle pressioni sia in condizioni termiche rappresentative sia in condizioni di carico elevato. Rischio e affidabilità sono valutati mediante un'analisi strutturata delle interfacce, ispirata ai principi DFMEA e supportata da verifiche di assemblaggio e manutenibilità.

Il contributo della tesi consiste nella formalizzazione di una metodologia di validazione pragmatica e coerente con il contesto industriale per hardware integrato su macchina. Combinando una definizione disciplinata dei vincoli con simulazioni mirate e giudizio ingegneristico, il lavoro dimostra la coerenza strutturale e termica di un artefatto vincolato e definisce una configurazione tecnica di riferimento idonea alla realizzazione industriale.

Acknowledgements

I would like to express my sincere gratitude to Prof. Massimiliano Annoni for the opportunity to carry out this thesis within the PoliMill laboratory, and for defining the academic and manufacturing-oriented framework in which this work was developed.

I am particularly grateful to Francesco Barna for his guidance during the intensive phases of the project, for his availability during critical moments, and for the in-depth technical discussions that contributed significantly to the refinement of the design and its manufacturability. His feedback was instrumental in translating design intent into a coherent and physically credible system.

I would also like to acknowledge Rifaa Javed, my partner in this project, for his collaboration throughout the development of the thesis. His contributions and shared responsibility across the design development and architectural direction of the work were essential to the completion of this project.

I would like to thank the PoliMill team for providing access to the laboratory facilities and for fostering a collaborative environment that enabled direct engagement with real manufacturing constraints, which strongly influenced the approach adopted in this work.

Finally, I would like to thank my family and close friends for their continued support, patience, and encouragement throughout this academic journey, and Furqan Ahmed for his valuable assistance with the CFD studies that supported the thermal and fluid-dynamic analyses presented in this thesis.

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List of Abbreviations

CNC Computer Numerical Control

CPU Central Processing Unit

GPU Graphics Processing Unit

PCIe Peripheral Component Interconnect Express

DIN Deutsches Institut für Normung

TS 35 35 mm top-hat DIN rail profile

IEC International Electrotechnical Commission

ISO International Organization for Standardization

ETSI European Telecommunications Standards Institute

IP Ingress Protection

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASME American Society of Mechanical Engineers

ASTM ASTM International

IEEE Institute of Electrical and Electronics Engineers

DFMEA Design Failure Mode and Effects Analysis

CFM Cubic Feet per Minute

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01

Scope and Position of the Engineering Investigation

This chapter defines CNC machining environments as persistent physical constraints and positions industrial edge devices as physically embedded compute nodes subject to mechanical, thermal, and environmental exposure. It establishes the purpose, scope, and ownership of claims of the validation-oriented investigation, delimiting analytical boundaries and excluding certification or optimisation objectives.

Chapter 1

Scope and Position of the Engineering Investigation

1.1 CNC Machining Environments as Persistent Physical Contexts

CNC machining environments represent one of the most physically demanding contexts within contemporary digital manufacturing, not because of isolated extreme events, but because of the sustained coexistence of multiple stress-inducing phenomena. Modern machine tools operate under high material removal rates, multidirectional cutting forces, and extended duty cycles characteristic of automated production systems. Hardware deployed in proximity to these machines is therefore subjected to conditions that act continuously over time rather than as rare or accidental anomalies [1, 2].



Figure 1.1: Machine-Integrated Edge Device Deployment Context

Such environments impose a combination of physical stressors, including airborne metal chips generated during cutting operations, liquid coolants used for lubrication and thermal control, and mechanical vibrations transmitted through spindles, machine frames, and shop-floor foundations. Although each stressor operates through a distinct physical mechanism, their combined effect reduces the predictability and stability of interfaces, surfaces, clearances, and assemblies. For equipment integrated close to the machining process, this reduction in predictability constitutes a first-order engineering condition rather than a secondary environmental consideration.

Cutting fluids, typically oil–water emulsions or synthetic formulations, are continuously circulated and atomised during machining. Mist and splashing deposit films on surrounding surfaces and migrate into crevices, joints, and interfaces. This is not merely a cleanliness concern. Fluid residues modify friction conditions at mechanical interfaces, promote contaminant accumulation, and create conductive or corrosive pathways in regions where connectors and contacts depend on stable surface states [3]. In this context, enclosure openings, joints, and seams become active engineering interfaces whose geometry and orientation directly influence long-term reliability.

In parallel, metal chips are expelled at high velocity and accumulate dynamically around the machine. Fine particulate debris behaves as an abrasive contaminant capable of clogging vents and eroding exposed edges, while larger fragments introduce localised impact and wedging risks at openings and recesses. Any strategy involving ventilation or access must therefore be treated as a controlled interface problem. Openings cannot be assumed to interact with a benign ambient environment; geometry must explicitly manage ingress pathways, debris trajectories, and accumulation zones [1, 2].

Mechanical vibrations propagate through machine structures and supporting foundations and are often amplified during high-speed operations and aggressive tool–workpiece interactions. The primary engineering concern is not immediate structural failure but cumulative architectural consequences, including gradual fastener preload variation, fretting at contact interfaces, fatigue initiation at local stress concentrators, and unintended resonance of slender or unsupported features [4, 5]. For reference, industrial machines evaluated under ISO 20816-3 commonly exhibit vibration velocity levels on the order of approximately 2.8–7.1 mm/s RMS during acceptable to unsatisfactory operating conditions, depending on machine class and power rating. Such magnitudes illustrate that machine-coupled equipment is exposed to sustained dynamic excitation rather than negligible ambient disturbance.

Beyond localised mechanical effects, CNC shop-floor environments are typically characterised by continuous operation, variable thermal conditions, and fluctuating humidity associated with coolant use and ventilation practices. Over extended periods, these factors introduce thermal cycling, condensation risk, and accelerated residue formation. Equipment operating in close proximity to machining processes must therefore reconcile material compatibility, mechanical durability, thermal behaviour, and interface stability under conditions that resist simplification. The machining environment is not a background variable; it constitutes a persistent physical constraint that conditions the plausibility of machine-adjacent deployment.

1.2 Industrial Edge Devices as Physically Embedded Compute Nodes

Within digital manufacturing and Industry 4.0 architectures, industrial edge devices function as distributed computational nodes responsible for acquiring, processing, and relaying data at the point of production. Their value lies in locality: by performing computation

close to the process, edge devices reduce reliance on centralised infrastructures, enable lower-latency data handling, and support responsive monitoring, anomaly detection, and adaptive control strategies [6, 7].



Figure 1.2: System Architecture Overview (Types of Devices Within Machine Systems)

Unlike centralised servers or purely virtualised systems, industrial edge devices are deployed in direct physical proximity to machine tools and production assets. They are integrated into shop-floor infrastructure such as control cabinets, machine frames, or auxiliary mounting structures to access sensor data generated during operation [6]. This physical embedding is not incidental. It fixes spatial orientation, constrains access directions, defines mounting interfaces, and mechanically couples the device to the surrounding machine environment.

Because the device is physically embedded, it must reconcile domains often treated independently. Computational reliability and connectivity must coexist with mechanical stability under vibration, predictable thermal behaviour under sustained internal heat generation, and controlled environmental exposure at openings, joints, and interfaces. The industrial edge device therefore occupies a hybrid position: it is simultaneously a computing node and a material artefact subject to load paths, clearances, contamination mechanisms, and assembly constraints. The credibility of the digital function is preserved only if the physical host maintains mechanical integrity, thermal compatibility, and service accessibility under shop-floor conditions.

1.3 Purpose of the Engineering Investigation

This thesis presents a validation-oriented engineering investigation of a machine-adjacent industrial edge device intended for deployment in CNC machining environments. The enclosure architecture, installation logic, manufacturing approach, material system, and internal component layout are treated as fixed boundary conditions. Within these constraints, the purpose of the investigation is to assess physical plausibility and robustness under representative operating conditions, rather than to pursue geometric redesign, performance

maximisation, or exhaustive numerical optimisation.

Engineering analysis is framed as an interpretive instrument applied to a predetermined configuration. The investigation evaluates whether the fixed configuration exhibits coherent mechanical behaviour under installation and handling loads, credible interface behaviour under vibration exposure, and physically consistent ventilation intent under simplified airflow assumptions. Risk and reliability considerations are addressed by identifying credible failure mechanisms at critical interfaces and examining whether the configuration incorporates robustness-supporting characteristics consistent with industrial interaction realities.

1.4 Scope, Boundaries, and Ownership of Claims

The scope of this thesis is limited to validation-oriented evaluation of the physical credibility of the machine-integrated enclosure configuration. It includes:

- Definition of the operating context and system boundary conditions.
- Selection and justification of analytical tools used for plausibility assessment.
- Simulation-supported mechanical plausibility assessment.
- Airflow organisation and ventilation verification under stated modelling limits.
- Configuration-level reliability and robustness interpretation including DFMEA as a structuring framework.
- Assembly, installation, and maintainability verification to ensure consistency between analytical validation and real interaction scenarios.

Explicitly excluded are electronic circuit design, firmware or software development, digital twin implementation, and benchmarking of computational performance. The thesis does not claim certification-level validation, compliance qualification, or probabilistic lifetime prediction. Conclusions are restricted to the evaluated configuration under the stated assumptions and representative conditions and are presented as engineering judgements supported by targeted analysis rather than universal performance claims.

02

System Definition and Assumptions

This chapter defines the environmental operating envelope, DIN rail installation logic, vibration exposure assumptions, and predefined electronic architecture governing the evaluated device. It establishes these conditions as non-negotiable boundary constraints that structure all subsequent mechanical, thermal, and reliability plausibility assessments.

Chapter 2

System Definition and Assumptions

2.1 Environmental Operating Envelope for Machinery-Mounted Electronics

Environmental parameter	Unit	3K3	3K5
Low air temperature	°C	+5	-5
High air temperature	°C	+40	+45
Low relative air humidity	%	5	5
High relative air humidity	%	85	95

Table 2.1: Environmental severity parameters according to IEC 60721-3-3 (Classes 3K3 and 3K5).

Electronic equipment deployed in proximity to industrial machine tools operates within environmental conditions that differ substantially from office-grade installations and electronics housed inside sealed electrical cabinets. In CNC machining facilities, even devices mounted outside the primary cutting envelope remain exposed to the ambient characteristics of the production hall, including airborne particulates, oil mist, humidity fluctuations, and sustained thermal variation associated with continuous operation. These conditions act persistently over time and must therefore be treated as normal operating exposure rather than exceptional disturbance [8].

IEC 60721-3-3 defines environmental severity classes for stationary equipment used at weather-protected locations, including production halls where oil mist, dust, and uncontrolled humidity are present [8]. Within this framework, Class 3K3 environments are characterized by moderate airborne contamination, relative humidity variation, and temperature ranges typical of industrial interiors, while excluding direct exposure to liquid jets or solid particle impact. This classification is adopted as the baseline environmental envelope for the evaluated device, consistent with machine-adjacent deployment outside the machining enclosure.

Indirect contaminationsuch as oil aerosols settling on surfaces, fine dust ingress through ventilation openings, and condensation driven by temperature cyclingconstitutes a long-

term exposure condition. Over extended service life, such factors influence material degradation, connector reliability, and thermal behavior even in the absence of direct coolant splash or chip impact [8]. Complementing environmental classification, the IEC 60068-2 series provides standardized environmental test methods relevant to temperature cycling, humidity variation, and mechanical disturbance. IEC 60068-2-30 formalizes cyclic damp heat exposure, representing condensation and moisture-related stresses encountered in industrial interiors [9]. These standards are not used here as prescriptive design checklists, but as justification for treating environmental exposure as technically characterizable and repeatable.

ETSI EN 300 019-1-3 further classifies controlled indoor environments for telecommunications and industrial electronics deployed at weather-protected locations [10]. Together, these standards establish a clear distinction: machinery-mounted electronics can be shielded from direct process hazards while remaining continuously exposed to the ambient realities of industrial production spaces. This distinction grounds all subsequent environmental and reliability assumptions used in the validation chapters.

2.2 DIN Rail Mounting as a Non-Negotiable Installation Boundary Condition



Figure 2.1: DIN Rail Interface Geometry and Mounting Logic

Installation logic exerts a decisive influence on the physical configuration of industrial electronic devices. In the present investigation, DIN rail mounting is treated as an imposed system constraint reflecting established industrial practice for modularity, interchangeability, and serviceability. IEC 60715 standardizes the geometry of DIN rails, most commonly the 35 mm top-hat rail, defining uniform snap-fit mounting interfaces for modular equipment [11].

Adoption of DIN rail mounting constrains device orientation, front-access philosophy, and spatial envelope. Vertical panel installation fixes gravity direction relative to internal components, influences airflow orientation, and establishes front-facing access as the primary service interaction mode. Maintainability expectations consistent with IEC 60204-1 reinforce this front-access assumption for machine-adjacent electrical equipment [12].

Thermal behavior is also conditioned by DIN rail practice. Manufacturer guidance for modular equipment typically recommends minimum spacing between adjacent modules to maintain convective airflow and to avoid thermal derating at elevated ambient temperatures [13]. In this thesis, such guidance justifies treating vent placement, airflow directionality, and spacing as boundary conditions rather than arbitrary stylistic decisions.

Mechanical stability under vibration further elevates the DIN rail interface from a mounting convenience to a structural boundary. IEC 60721-3-3 and IEC 60068-2-6 assume secure retention of snap-mounted devices under continuous excitation [8, 14]. When equipment is mounted directly on machinery or machine frames, dynamic loads are transmitted through the DIN rail interface into the enclosure. The rail therefore defines a primary mechanical coupling path through which structure-borne vibration enters the device. Throughout this thesis, DIN rail mounting is treated as a system-level constraint governing spatial organisation, access logic, airflow intent, and mechanical load introduction.

2.3 Vibration Exposure Assumptions in Heavy CNC Installations

ISO 10816-3 Machinery Group 1-4

Velocity mm/s (RMS)	Group 2&4		Group 1&3	
	Flexible	Rigid	Flexible	Rigid
11	Damage Occurs			
7.1				
4.5	Restricted operation			
3.5	Unrestricted operation			
2.8				
2.3				
1.4	Newly Commissioned			

Displacement um (peak-peak)	Group 4		Group 3	
	Rigid	Flexible	Rigid	Flexible
396	Damage Occurs			
320				
255				
158				
102	Restricted operation			
79	Unrestricted operation			
62				
51				
31	Newly Commissioned			

Figure 2.2: Vibration Classification Zones (ISO 10816).

Vibration constitutes a defining characteristic of machinery-mounted electronic equipment, particularly when installed on heavy, floor-mounted CNC machines. Unlike transport shock events, operational vibration arises from structure-borne excitation generated during normal machine operation. IEC 60721-3-3 frames vibration exposure for stationary equipment as continuous excitation with superimposed transient components [8]. In production halls housing large machine tools, vibration is transmitted through machine frames, foundations, and mounting structures, resulting in persistent excitation across low- to mid-frequency ranges.

IEC 60068-2-6 formalizes sinusoidal vibration testing representative of steady frequency-dependent excitation such as rotating spindles and axis drives [14]. IEC 60068-2-64 addresses broadband random vibration associated with mixed operational spectra and intermittent disturbances linked to machine dynamics [15]. These standards support modeling vibration exposure as a combined background-and-transient condition relevant to retention, preload stability, and interface robustness.

ISO 10816-3 categorizes vibration levels for large, floor-mounted industrial machines based on measurements on non-rotating parts [16]. Machines operating within acceptable to unsatisfactory zones commonly exhibit vibration velocity levels on the order of approximately 2.8–7.1 mm/s RMS, depending on machine class and condition. While these values are not directly imposed as input loads in this chapter, they illustrate that machine-mounted equipment is exposed to sustained dynamic excitation of non-negligible magnitude. Within this thesis, vibration is treated as a continuous operating condition informing mechanical plausibility assessment and interface risk reasoning.

2.4 Predefined Electronic Architecture and Internal Mechanical Constraints

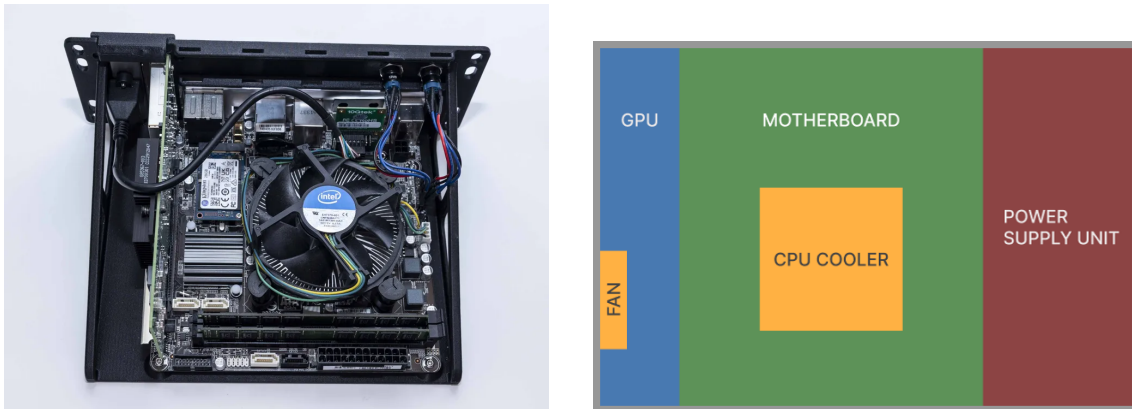


Figure 2.3: Internal Electronic Architecture Layout

The internal electronic configuration of the device is treated as a predefined subsystem established prior to, and independently from, the validation investigation. The electronic architecture is based on standardized embedded computing components selected to support local data processing typical of industrial edge applications. The purpose of this thesis

is not to redesign electronic functionality, but to evaluate whether the fixed physical integration of these components remains mechanically and thermally plausible under the declared operating conditions.

The system is organised around a mini-ITX motherboard hosting the central processing unit, memory modules, and primary expansion interfaces. Expansion capability is provided through a single-slot PCIe graphics processing unit mounted directly to the motherboard. The mass of the graphics module introduces a potential bending moment at the PCIe connector under vibration excitation if left unsupported.

To mitigate this condition, a secondary mechanical retention element is incorporated as part of the enclosure architecture. This element provides structural support at the distal edge of the graphics module, linking it mechanically to the enclosure frame. Under vibration excitation, inertial loads generated by the graphics module mass are therefore transferred into the enclosure structure through this secondary support rather than being concentrated at the PCIe electrical connector. The PCIe interface is thus treated primarily as an electrical connection rather than as a cantilevered structural restraint. This load-path redistribution reduces connector stress, limits relative displacement between card and motherboard, and supports vibration robustness at the configuration level.

Power delivery is provided by a passively cooled power supply mounted as an independent module within the enclosure. Together, the processing unit, graphics module, and power supply establish a system characterized by spatially concentrated heat sources with differing cooling dependencies. Active cooling is mandatory for the central processor, while the graphics unit and power supply rely on a combination of local airflow and overall enclosure ventilation.

Airflow is therefore treated as a system-level architectural requirement rather than an isolated component feature. External interfaces and access assumptions are defined by the internal architecture and DIN rail installation logic, resulting in front-facing interaction consistent with vertical mounting practice. Internal volume is assumed to accommodate pragmatic cable routing and strain relief, acknowledging variability in harness stiffness, connector geometry, and service handling.

The enclosure front panel interface is defined as a micromilled aluminium-to-aluminium perimeter contact without elastomeric or compressive sealing elements. Environmental separation is achieved through controlled surface flatness and distributed fastener preload rather than deformation-based sealing. No IP-rated enclosure classification is claimed, and ingress control is treated as a function of geometric precision and interface stability under vibration rather than as hermetic sealing.

These predefined internal constraints—fixed component envelopes, localized thermal generation, mixed cooling dependencies, mechanically sensitive expansion interfaces, and defined load-transfer paths—are treated as non-negotiable boundary conditions for all subsequent plausibility assessments presented in this thesis.

03

Manufacturing and Assembly as Physical Boundary Conditions

This chapter positions manufacturing strategy, tool accessibility, geometric stabilisation, and tolerance localisation as physical boundary conditions governing the enclosure architecture. It establishes five-axis CNC milling and assembly realism as credibility filters that delimit geometrical plausibility prior to subsequent validation activities.

Chapter 3

Manufacturing And Assembly As Physical Boundary Conditions

3.1 Manufacturing Strategy As A Physical Boundary Condition

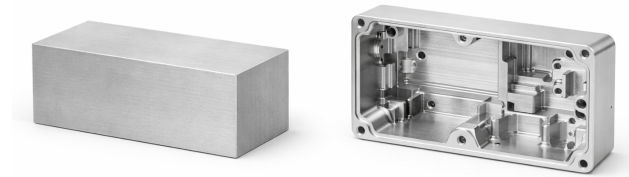


Figure 3.1: Monolithic Machining Strategy (Billet and Machined Body)

Within this thesis, manufacturing strategy is not treated as a downstream feasibility check or a vehicle for geometric refinement, but as a defining physical boundary condition that constrains the validity of subsequent engineering assessment [17, 18]. Once system architecture, enclosure geometry, material selection, and interface hierarchy are fixed, manufacturing acts as a selective filter: only those portions of the defined geometry that remain physically realizable under controlled industrial conditions are retained as credible [19].

Five-axis CNC milling is adopted as a necessary condition for preserving geometric continuity inherent to the enclosure architecture [20, 21]. The enclosure incorporates non-prismatic volumes, locally thickened regions, and multi-directional interfaces that cannot be realized coherently under three-axis constraints without segmentation. Such segmentation would introduce additional fasteners, alignment tolerances, and geometric discontinuities, fundamentally altering load transfer paths, thermal behaviour, and assembly logic [18, 22]. The monolithic body is therefore not a stylistic decision, but a structural consequence of

enforcing architectural continuity under realistic subtractive manufacturing constraints.

Machining from solid billet reinforces this logic. Alternative approaches folded sheet metal, assembled sub-components, or hybrid constructions were excluded early because they would impose planar surface logic, restrict localized thickening, and fragment continuous boss and interface geometries required for structural robustness [18, 23]. Manufacturing strategy thus constrains the geometry to the subset that remains continuous, accessible, and mechanically coherent when realized through conventional five-axis subtractive processes.

Standardized mounting elements such as the DIN rail interface are intentionally excluded from the monolithic body and treated as purchased components. This separation prevents external geometric conventions from distorting the enclosure architecture while allowing manufacturing constraints to operate directly on the primary structural volume [18].

3.2 Tool Accessibility, Setup Logic, And Geometric Consequences

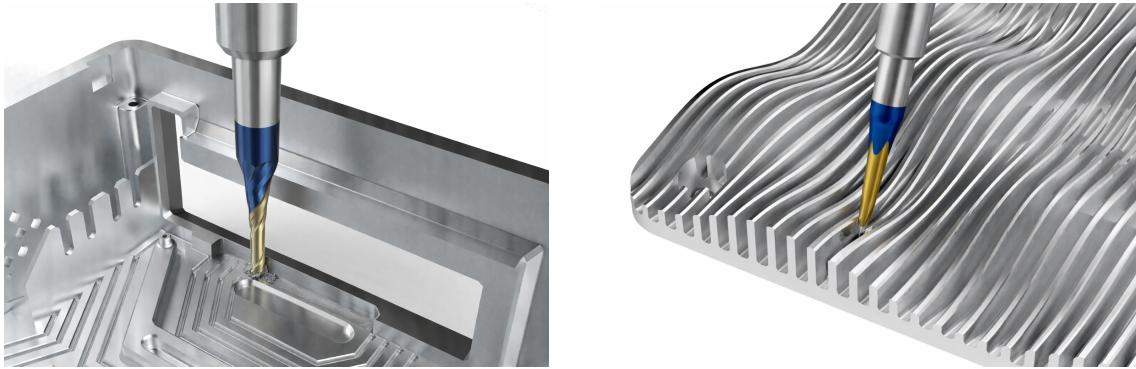


Figure 3.2: Tool Accessibility and Setup Orientation

Tool accessibility is addressed as a direct geometric consequence of internal organization and interface layout. All internal cavities, mounting features, and interface regions are configured to remain accessible within conventional five-axis tool orientations, without reliance on undercuts or non-standard tooling [20, 21]. Sharp internal corners are systematically avoided because they would either be unmachinable or would require tool approaches incompatible with surface continuity and feature alignment [20].

Feature proportions are constrained to avoid slender cutting conditions associated with excessive depth-to-diameter ratios in end-mill operations. Pocket depths, boss heights, and internal channel geometries are dimensioned to remain within regimes compatible with stable tool engagement, limited deflection, and acceptable surface integrity in aluminium machining [20, 24]. Where geometry approaches machining stability limits, material is added locally rather than removed globally, preserving stiffness and cutting stability without introducing secondary reinforcement elements.

Multiple machining setups and re-clamping operations are accepted where required to preserve geometric intent. Completion within a single setup is explicitly rejected as a governing objective, as it would necessitate reduced cavity depth, compromised wall transi-

tions, or altered feature orientation [21]. Re-clamping is therefore treated as procedural cost rather than architectural compromise.

Manufacturability constrains geometry through localized stabilization and accessibility control rather than through global simplification. The resulting enclosure represents the subset of the architectural definition that remains physically realizable under controlled, conventional five-axis machining conditions [20, 21].

3.3 Geometry Stabilisation Under Manufacturing Constraint

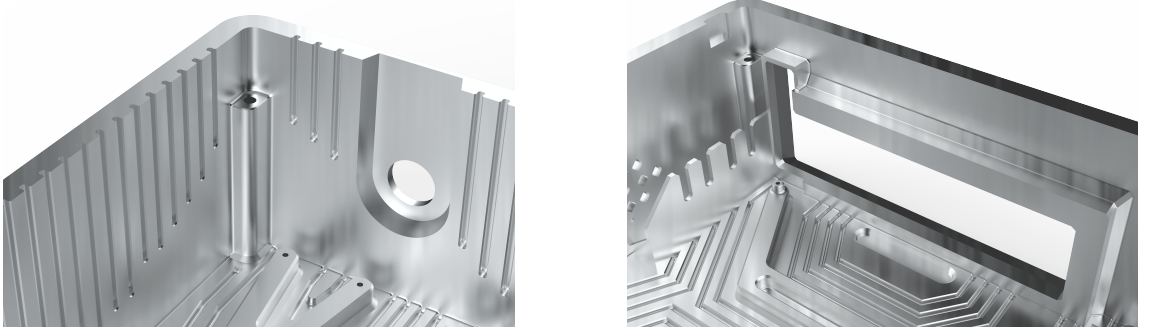


Figure 3.3: Structural Considerations in Stress-Prone Areas.

When subjected to manufacturing constraints, geometric stabilization occurs through elimination of fragile or non-repeatable features rather than through architectural redesign [17, 18]. Manufacturing feedback does not introduce new structural concepts; instead, it enforces limits on slenderness, depth, sectional transition, and unsupported material regions that would compromise repeatability or surface integrity [20].

Thin ribs, isolated bosses, and locally weakened wall sections are deliberately avoided. Where fastening or mounting loads are present, material is added through continuous thickening rather than secondary brackets or inserts. This approach preserves uninterrupted load paths through the monolithic body and avoids geometrically sensitive features vulnerable to tool deflection, vibration, or tightening-induced stress [20, 22].

Early geometric alternatives relying on narrow internal pockets, high depth-to-width ratios, or abrupt sectional transitions were excluded because they would require conservative cutting parameters or introduce localized compliance incompatible with the enclosures structural logic [20, 21]. Thickness is therefore not treated as a stress-minimized optimization variable; instead, it emerges as a consequence of machining stability, interface integration, and continuous load-path preservation. Structural verification confirms the plausibility of this geometry rather than determining it.

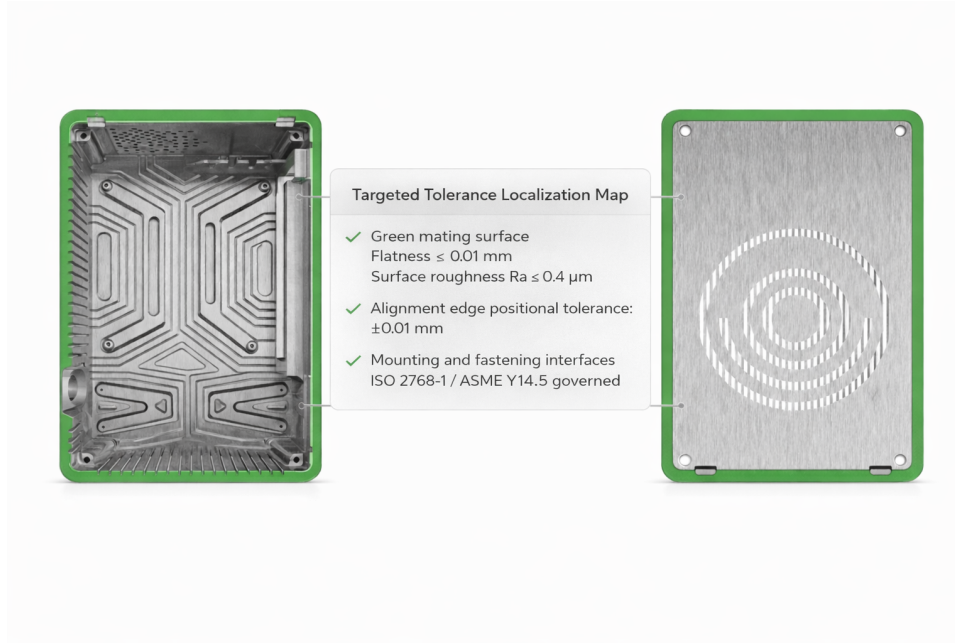


Figure 3.4: Tolerance Localisation at Critical Interfaces

3.4 Interface Precision And Tolerance Localization

Dimensional precision is applied selectively, only where deviation would produce functional or mechanical consequence [22, 25]. Controlled tolerances are localized to the DIN rail mounting interface, threaded fastener bosses, front panel mating surfaces, and perimeter contact interfaces.

At the DIN rail interface, tolerances ensure reliable engagement, predictable load transfer, and stable retention under vibration. Excessive clearance would introduce positional instability; overly restrictive control would increase sensitivity to variation and complicate installation [18, 26]. The tolerance regime therefore balances mechanical stability with assembly practicality.

Threaded boss geometry is dimensioned to preserve preload retention while avoiding localized material overstress during tightening and vibration exposure. Tolerance control mitigates risks such as thread stripping, crack initiation, and loss of clamping force [22]. Similarly, the front panel mating interface and perimeter contact surfaces are controlled to ensure repeatable surface contact and preload distribution, limiting uncontrolled ingress while preserving deliberate airflow pathways [25].

Internal clearance volumes and non-contact surfaces are intentionally relaxed. These regions accommodate manufacturing variability, thermal expansion, and assembly freedom without affecting functional performance [25, 26]. Precision is therefore applied only where it generates physical consequence, avoiding unnecessary manufacturing burden while preserving reliability.

3.5 Manufacturing Strategy As Physical Credibility Filter

The adopted manufacturing strategy establishes the physical credibility of the enclosure architecture rather than refining or optimizing its form [17, 18]. Monolithicity, feature accessibility, interface definition, and tolerance localization collectively define the domain within which the enclosure can be considered manufacturable, repeatable, and structurally coherent.

Manufacturing and assembly considerations therefore delimit the region of geometrical plausibility within which subsequent mechanical validation, airflow verification, and risk assessment remain meaningful. By enforcing realistic production constraints and excluding speculative assumptions, this chapter provides the physical grounding required for the engineering evaluations presented in the chapters that follow [18, 22].

04

Material Assumptions and Physical Property Definition

This chapter declares Aluminium alloy 7075 as the fixed material system supporting mechanical, thermal, and assembly plausibility assessments. It defines property assumptions, surface condition logic, and environmental implications as stabilising inputs for consistent interpretation of subsequent validation results.

Chapter 4

Material Assumptions And Physical Property Definition

4.1 Role Of Material Assumptions In Engineering Validation

Within the methodological framework of this thesis, material definition is treated as a fixed input required for physically credible engineering validation rather than as a variable subject to optimization [27]. Once enclosure architecture, geometry, and manufacturing strategy are established as boundary conditions, material properties define the mechanical, thermal, and assembly-related behaviour against which plausibility assessments are conducted [28].

The objective of this chapter is therefore not to compare alternative candidate materials or justify an optimal selection, but to explicitly declare the reference material system assumed throughout subsequent analyses. By fixing material behaviour in advance, the validation results presented in later chapters can be interpreted consistently, without conflating analytical outcomes with unresolved material decisions [27].

4.2 Operating Context And Implied Material Requirements

The device is intended for deployment in weather-protected industrial environments typical of CNC machining installations. In such contexts, exposure to oil mist, airborne particulates, humidity variation, and sustained machine-induced vibration is expected, while direct exposure to coolant jets, abrasive chip impact, or outdoor climatic loading is excluded by the defined installation position [8].

Under these conditions, the enclosure material must provide sufficient stiffness to preserve geometric stability under self-weight, vibration excitation, and handling loads while maintaining alignment at mounting interfaces and fastening features [29]. Excessive mass is undesirable due to its influence on DIN rail mounting loads, vibration response, and installation ergonomics [4].

From a thermal perspective, the enclosure is assumed to function as a structurally conductive body that supports predictable heat spreading from internal components and provides

a stable boundary for airflow-driven cooling. It is not intended to operate as a primary external heat sink through extended finning, but rather as a thermally coherent enclosure that complements active cooling mechanisms and internal airflow organization [28].

Manufacturing constraints further inform material requirements. The enclosure body and front panel are realized as monolithic components via five-axis CNC milling. The selected material must therefore support precise subtractive machining, stable cutting behaviour, predictable tool engagement, and repeatable feature definition without reliance on secondary joining processes or corrective post-machining operations [20, 30].

4.3 Assumed Material System: Aluminium Alloy 7075

Property	Value
Density	2810 kg m ⁻³
Young's Modulus	71.7 GPa
Poisson's Ratio	0.33
Bulk Modulus	70.29 GPa
Shear Modulus	26.96 GPa
Tensile Yield Strength	503 MPa
Compressive Yield Strength	503 MPa
Tensile Ultimate Strength	572 MPa

Table 4.1: Aluminium 7075 Mechanical Property Summary

Based on the predefined architectural, manufacturing, and operational constraints, Aluminium alloy 7075 is adopted as the reference material for all machined enclosure components, including the primary enclosure body and front ventilation panel. This selection is treated as a declared boundary condition for validation rather than the outcome of a comparative optimization exercise [27].

Aluminium 7075 provides high specific stiffness and strength, supporting compact wall sections, integrated mounting features, and locally thickened regions without excessive mass [31, 32]. In commonly supplied heat-treated conditions such as T6 or T651, the alloy exhibits a Young's modulus on the order of approximately 70–72 GPa, a yield strength typically exceeding 450 MPa, and a density of approximately 2,800 kg m⁻³ [29, 31, 33]. These properties are consistent with the monolithic enclosure strategy and contribute to stable behaviour under vibration and service-related mechanical loads.

From a thermal standpoint, Aluminium 7075 exhibits a thermal conductivity typically in the range of approximately 130–160 W m⁻¹ K⁻¹, depending on temper and product form [31]. While lower than commercially pure aluminium, this conductivity remains sufficient to support effective in-plane heat spreading within the enclosure body. In the present configuration, the enclosure is assumed to act as a thermally coherent structural boundary that complements airflow-driven cooling rather than as a high-efficiency external finned heat sink.

The alloy's suitability for precision CNC machining enables the realization of complex

internal geometries, controlled fillet radii, and consistent surface definition within a conventional five-axis subtractive manufacturing process [20, 30]. Heat treatment condition is assumed fixed and is not treated as a variable within the scope of this work [31, 33].

4.4 Surface Condition And Treatment Assumptions

Although Aluminium 7075 provides favourable mechanical performance, its zinc-rich composition results in lower intrinsic corrosion resistance compared to lower-strength aluminium alloys [33]. In industrial environments characterized by humidity and oil mist, surface condition therefore represents a relevant consideration for long-term durability [8, 33].

For the baseline configuration evaluated in this thesis, the enclosure is assumed to retain an as-machined surface finish. This assumption preserves dimensional control, avoids additional process variability, and maintains predictable mechanical and thermal behaviour for validation activities [30].

Surface treatments such as anodic oxidation are recognized as beneficial under increased environmental severity or extended service exposure, improving corrosion resistance and surface stability [34]. However, such treatments introduce additional processing steps and dimensional variability. They are therefore treated as conditional enhancements rather than mandatory attributes of the reference configuration.

4.5 Implications For Validation And Assembly Behaviour

The assumed material system directly influences mechanical plausibility, fastening behaviour, and assembly robustness. The stiffness and strength of Aluminium 7075 support integration of threaded bosses, mounting blocks, and interface features directly into the enclosure body, reducing part count and eliminating secondary joining elements [29, 18].

Controlled elastic behaviour and stable surface definition enable reliable fastener preload retention and stable metal-to-metal interface contact at panel interfaces under vibration and service loading [29]. By treating surface treatment as a conditional enhancement rather than a fixed requirement, the validation framework remains applicable across a range of realistic industrial deployment scenarios.

Material assumptions are therefore not presented as isolated design decisions, but as enabling physical conditions that stabilize the enclosure architecture and support consistent interpretation of mechanical, thermal, and risk-related validation outcomes in subsequent chapters [27, 28].

05

Validation Philosophy and Method Selection

This chapter defines validation as a plausibility-oriented engineering activity applied under fixed architectural and material constraints. It establishes the role of engineering judgement, the scope of analytical tools, modelling assumptions, and limits of applicability governing all subsequent simulation and risk assessments.

Chapter 5

Validation Philosophy And Method Selection



Figure 5.1: Validation Framework: Boundary Conditions Analysis Judgement

5.1 Purpose Of Validation In This Thesis

The purpose of validation in this thesis is not to optimise performance, certify compliance, or predict probabilistic lifetime behaviour, but to assess the physical plausibility and robustness of a fixed enclosure configuration under representative industrial conditions. Validation is therefore treated as an interpretive engineering activity, aimed at excluding physically adverse behaviour and confirming consistency between assumed operating conditions, structural configuration, and interaction scenarios.

The enclosure architecture, material system, manufacturing strategy, and installation logic are treated as fixed boundary conditions inherited from the preceding design definition. Within this context, validation serves to test whether these boundary conditions lead to credible mechanical, thermal, and interaction behaviour when subjected to representative loads, environmental exposure, and handling scenarios. The objective is not to demonstrate optimality, but to confirm that the configuration behaves coherently within its intended scope of use.

This validation stance reflects common industrial practice in early-stage or constraint-driven development, where engineering analysis is employed to support informed judgement under limited time, data, and iteration freedom, rather than to establish exhaustive numerical proof.

5.2 Role Of Engineering Judgement Under Constraint

Engineering judgement plays a central role in the validation process adopted in this thesis. Numerical analysis, risk assessment, and procedural verification are treated as supporting instruments rather than autonomous decision-makers. Their outputs are interpreted in light of geometric intent, interface logic, manufacturing realism, and known industrial behaviour.

This approach acknowledges the inherent limitations of numerical models when applied to machine-integrated artefacts operating in complex industrial environments. Simplifications in material behaviour, boundary conditions, load application, and environmental representation are unavoidable. As a result, numerical outputs are not interpreted as absolute predictors of real-world behaviour, but as indicators of trends, sensitivities, and potential inconsistencies.

Engineering judgement is therefore exercised to determine whether observed behaviours are physically reasonable, whether adverse conditions are credibly excluded, and whether the configuration demonstrates sufficient robustness for its intended context. This judgement is informed by experience-based understanding of industrial machinery, manufacturing constraints, and service interaction, rather than by numerical thresholds alone.

5.3 Selection And Scope Of Analytical Tools

Analytical tools are selected in this thesis based on their ability to support plausibility assessment under fixed constraints, rather than their capacity to enable optimisation or exhaustive performance evaluation. Each tool is employed with a clearly defined scope and limitation.

Structural numerical analysis is used to assess deformation tendencies, load transfer paths, and stress distribution under representative mechanical loads associated with installation, handling, and operation. The intent is to identify gross inconsistencies, excessive compliance, or unrealistic load concentration, not to establish certified strength or fatigue life.

Computational airflow and thermal analysis are employed to examine airflow organisation,

heat spreading behaviour, and sensitivity to orientation or obstruction. These analyses are used to verify that the enclosures ventilation concept behaves coherently under simplified assumptions, rather than to predict precise temperature limits or validate thermal compliance.

DFMEA-based reasoning is used as a qualitative structuring framework to identify potential failure modes and their physical effects at critical interfaces. This approach supports systematic risk identification and interpretation without adopting formal scoring, prioritisation, or compliance-driven procedures.

The selection of these tools reflects a deliberate balance between analytical insight and industrial realism, ensuring that validation effort remains proportional to the development stage and decision-making context.

5.4 Assumptions, Simplifications, And Modelling Limits

All validation activities in this thesis are conducted under explicitly stated assumptions and simplifications. These include, but are not limited to, linear elastic material behaviour, representative static or quasi-static loading conditions, simplified thermal boundary conditions, and idealised contact or constraint definitions.

Environmental exposure is represented through bounding scenarios rather than detailed stochastic models. Vibration is treated implicitly through representative loading and interface robustness considerations rather than through full dynamic response modelling. Manufacturing variability and assembly tolerance effects are considered qualitatively at the interface level rather than through exhaustive statistical simulation.

These simplifications are intentional and consistent with the validation objective. They allow physically meaningful behaviour to be examined without introducing modelling complexity that would imply a level of predictive certainty beyond the scope of the thesis.

5.5 Scope Of Applicability And Non-Applicability

The conclusions drawn from the validation activities presented in subsequent chapters apply strictly to the evaluated enclosure configuration, under the stated assumptions and representative operating conditions. The results are intended to support engineering judgement regarding plausibility and robustness, not to serve as certification evidence or guarantees of long-term field performance.

The validation approach presented in this thesis is not applicable to configurations involving significant geometric modification, alternative material systems, different installation strategies, or substantially altered operating environments. Likewise, the results are not intended to replace detailed compliance testing, probabilistic reliability analysis, or certification-level verification.

By explicitly defining the scope and limits of applicability, this chapter establishes a clear framework within which subsequent validation results should be interpreted.

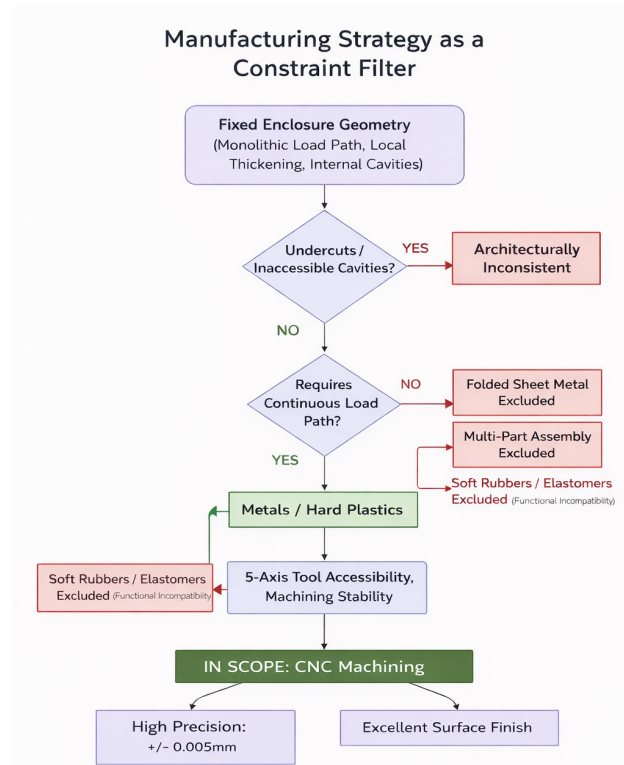


Figure 5.2: Scope of Applicability and Non-Applicability Diagram

5.6 Closing Note

This chapter defines the philosophical stance, analytical boundaries, and interpretive framework governing all validation activities presented in the remainder of the thesis. By clarifying the role, scope, and limits of engineering analysis before presenting any results, the work ensures that subsequent conclusions are read as disciplined assessments of physical plausibility under constraint, rather than as claims of optimisation or certification.

06

Mechanical Simulation and Structural Behaviour Assessment

This chapter presents static and modal simulations used to assess load transfer, deformation tendencies, and structural stiffness of the predefined enclosure under representative conditions. It excludes optimisation and certification objectives while confirming coherent behaviour within declared boundary assumptions.

Chapter 6

Mechanical Simulation and Structural Behaviour Assessment

6.1 Position of the Simulation Chapter Within the Validation Framework

This chapter presents the mechanical simulation studies conducted to assess the structural behaviour of the machine-integrated enclosure under representative installation and handling conditions. Simulation is employed strictly as a validation instrument to examine structural plausibility of the predefined architecture. No geometric optimisation, redesign, or performance maximisation was undertaken in response to analytical results.

The enclosure geometry, material definition (Aluminium 7075-T6), wall thickness distribution, and mounting interface logic were treated as fixed boundary conditions. The objectives of the analyses are therefore limited and explicit:

- To exclude excessive static compliance under gravity-dominated loading
- To examine load transfer paths through the resolved architecture
- To identify potential stress amplification near mounting interfaces
- To characterise inherent structural stiffness via modal analysis
- To detect the presence or absence of low-frequency global structural modes

Fatigue life prediction, impact simulation, machine-induced vibration amplitude quantification, and regulatory certification are outside the scope of this chapter.

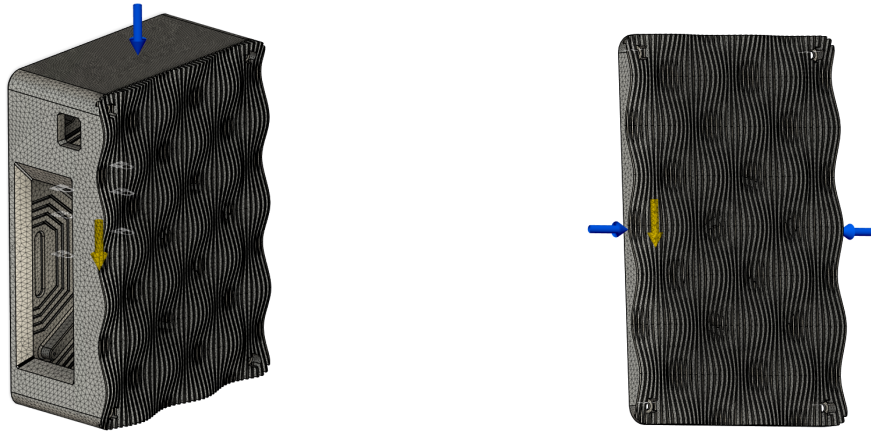


Figure 6.1: Structural Model Boundary Conditions and Constraints

6.2 Model Definition and Discretisation Strategy

6.2.1 Geometric Representation

The simulation model was derived directly from the resolved enclosure geometry. All load-bearing walls, ribs, mounting bosses, interface features, and thickness transitions were retained to preserve first-order stiffness characteristics. Non-structural cosmetic fillets and minor aesthetic details were suppressed only where required to improve solver robustness. No structural idealisation or analytical geometry simplification was introduced.

6.2.2 Material Definition

Material behaviour was defined as Aluminium 7075-T6 with the following parameters:

- Youngs modulus: 71–72 GPa
- Poissons ratio: 0.33
- Yield strength: 500 MPa
- Density: 2810 kg m⁻³

Linear elastic, homogeneous, isotropic behaviour was assumed. Plastic deformation, fatigue accumulation, creep, and strain-rate effects were not considered.

6.2.3 Mesh Definition and Quality Controls

All structural studies were discretised using second-order (parabolic) solid elements with curvature-aware meshing enabled. Mesh sizing was specified as a fraction of the model envelope, with:

- 3% average element size for full-body stress and panel bending studies

- 4% average element size for the modal study

Part-wise mesh scaling was enabled to preserve local geometric fidelity. Curved elements were permitted to better represent fillets and thickness transitions. Mesh quality controls limited element distortion, including a maximum aspect ratio of 10 and bounded adjacent size ratio (≤ 1.5), with minimum element size constrained to 20% of the average size.

Representative mesh statistics were:

- Full-body stress model: 789,319 nodes / 481,864 elements
- Panel bending model: 407,555 nodes / 230,947 elements
- Modal model: 377,177 nodes / 221,722 elements

No automatic adaptive refinement steps were employed in the final reported models. The selected mesh densities were chosen to balance geometric fidelity with computational stability while preserving first-order stress and displacement trends.

6.3 Boundary Condition Assumptions

Mounting interface regions corresponding to the machine attachment points were modelled using fully fixed translational constraints ($U_x = U_y = U_z = 0$). These constraints represent rigid attachment to the machine structure. While real fasteners exhibit finite compliance, the fully fixed assumption provides a conservative representation in terms of local stress concentration and slightly underestimates global displacement.

Gravity loading was applied as a global body acceleration of 9.807 m/s² in the negative Z-direction where relevant. No dynamic amplification factors were introduced in static simulations.

6.4 Static Structural Assessment

6.4.1 Purpose

Static analysis evaluates enclosure behaviour under gravity-dominated and installation-related loading scenarios. The purpose is to determine whether the architecture exhibits:

- Excessive deformation under self-weight
- Mounting plane bending tendencies
- Torsional distortion due to eccentric mass
- Stress amplification at interface regions
- Yield-adjacent stress magnitudes
- Three load cases were defined.

6.4.2 Load Case 1 Self-Weight of Enclosure

Load Introduction: Global gravitational acceleration applied as a body force. Mass distribution corresponds to enclosure geometry (56 kg). Mounting interface regions fully constrained.

Mechanical Intent: Represents installed operational condition without additional external loading. Intended to provoke global sagging behaviour and stress concentration at attachment regions.

Observation: Stress remains globally distributed with no local amplification at mounting interfaces. Deformation is minimal relative to geometric scale, and stress magnitudes remain negligible compared to yield strength. The enclosure behaves as a closed-section structural body.

6.4.3 Load Case 2 Self-Weight + Internal Component Mass

Load Introduction: Global gravitational acceleration applied. Internal electronics mass represented as consolidated distributed mass at mounting boss regions.

Mechanical Intent: Represents fully assembled configuration. Intended to examine eccentric mass-induced torsional bias and local stress amplification at internal interfaces.

Observation: A modest increase in stress near internal mounting regions is observed, consistent with expected load transfer. No asymmetric global distortion or torsional instability is detected. Load paths remain coherent.

6.4.4 Load Case 3 External Top Load While Suspended

Load Introduction: Mounting interfaces fully constrained. Uniform downward surface load applied across the top panel. The induced bending moment about the mounting plane is approximated as:

$$M = F \cdot d$$

where F is applied force and d is the vertical offset between load plane and mounting interface centroid.

Mechanical Intent: Represents handling or installation scenarios generating cantilever-type bending.

Observation: Stress gradients remain smooth and distributed. No yield-adjacent regions or sharp amplification occur. Deformation remains small relative to enclosure dimensions. The structure behaves as a torsion-resistant box rather than as independent plate elements.

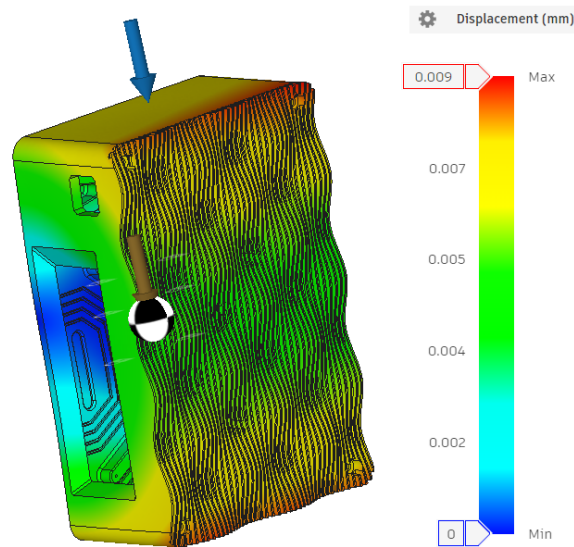


Figure 6.2: Total Displacement Distribution Under Maximum Static Load Condition

6.5 Localised Panel Bending Assessment

A representative load-bearing panel segment was evaluated under transverse loading with constrained edges.

Applied Force	Max Stress (MPa)	Max Displacement (mm)	Safety Factor
100 N	6.513	0.013	~77
50 N	3.268	0.007	~154
20 N	1.322	0.003	~380

Table 6.1: Local panel bending response under transverse loading.

Stress and displacement scale linearly with applied force, confirming elastic behaviour. Under 100 N, peak stress corresponds to 1.3% of yield strength and maximum displacement (13 μm) remains small relative to panel thickness and assembly tolerances. Excessive local compliance is therefore excluded under representative static interaction loads.

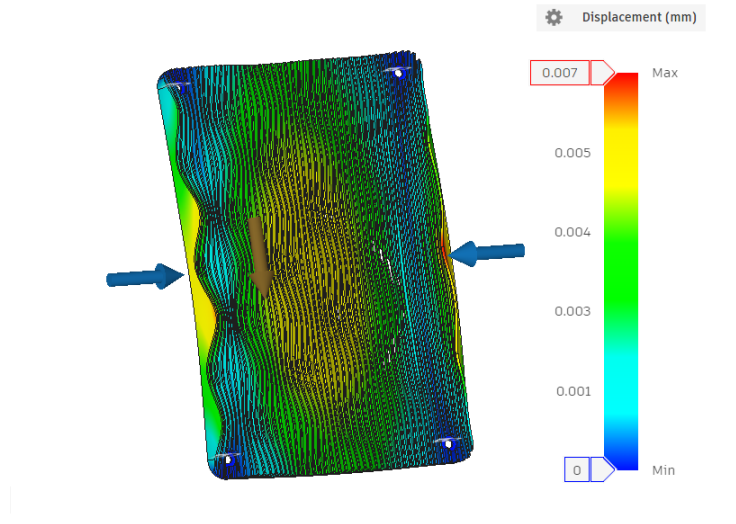


Figure 6.3: Local Panel Bending Displacement

6.6 Modal Assessment of Enclosure Dynamics

6.6.1 Objective

A linear free-vibration modal analysis was conducted to characterise inherent structural stiffness under installed boundary conditions. The objective is to determine whether the enclosure exhibits low-frequency global modes indicative of structural softness.

6.6.2 Modal Results

Under the defined mounting constraints, the first eight natural frequencies were:

- Mode 1: 164.267 Hz
- Mode 2: 214.455 Hz
- Mode 3: 332.62 Hz
- Mode 4: 597.491 Hz
- Mode 5: 801.604 Hz
- Mode 6: 895.00 Hz
- Mode 7: 1102.766 Hz
- Mode 8: 1283.207 Hz

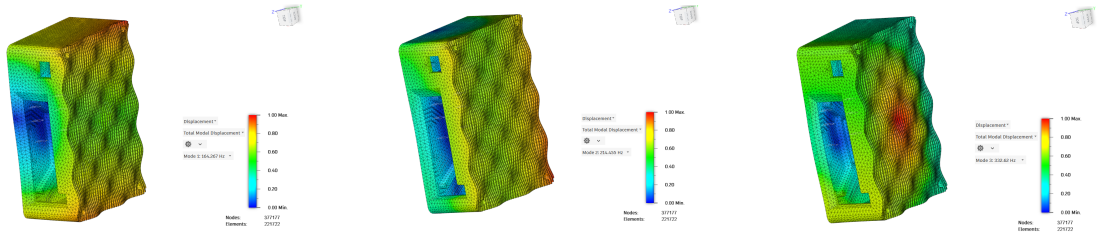


Figure 6.4: First three natural modes of the enclosure under fixed mounting constraints: 164.3 Hz, 214.5 Hz, and 332.6 Hz. Deformation visually amplified.

The first three modes exhibit distributed global bending and torsional characteristics rather than localized panel flutter. No abnormally low-frequency global structural modes were observed. The first global mode at approximately 164 Hz indicates that the enclosure does not behave as a compliant plate-dominated assembly under installed conditions.

The consistency between low static deflection under bending-dominated loading and modal stiffness (absence of sub-100 Hz global modes) indicates coherent structural hierarchy within the monolithic enclosure architecture.

6.7 Structural Behaviour Insights

Across static and modal analyses, the enclosure demonstrates consistent load transfer and structural integrity:

- Side walls act as primary bending members under cantilever loading.
- The top panel participates in compressive stress distribution during bending.
- Closed-section geometry resists torsional warping effectively.
- Mounting interfaces act as structural anchors without stress amplification.
- No stress concentration along mounting interface edges, excessive side-wall flexure, isolated panel bowing, or low-frequency global bending behaviour was observed.

6.8 Limitations

The analyses presented:

- Do not evaluate fatigue behaviour
- Do not predict machine-induced vibration amplitude
- Do not simulate impact events
- Do not constitute certification-level structural validation

Rigid mounting assumptions neglect fastener compliance, and real-world installation may introduce slightly greater displacement than predicted. The simulations are positioned strictly as plausibility-oriented validation tools within an industry-aligned engineering framework.

07

Airflow Organisation and Ventilation Verification

This chapter evaluates airflow topology and ventilation behaviour of the fixed enclosure architecture under representative and elevated internal heat loads. It verifies that forced convection remains organised and physically coherent without optimisation or thermal certification claims.

Chapter 7

Airflow Organisation and Ventilation Verification

7.1 Scope and Position of the Airflow Assessment

This chapter presents a structured assessment of airflow organisation and ventilation behaviour within the machine-integrated industrial edge device enclosure. The analysis is positioned as a plausibility and robustness verification exercise rather than a performance prediction or thermal certification study.

The enclosure geometry, internal component layout, vent configuration, and fan placement are treated as fixed architectural boundary conditions established in preceding chapters. Airflow and thermal simulations were conducted primarily within the Autodesk Fusion 360 Electronics Cooling environment, with airflow topology cross-verified using an independent ANSYS Fluent computational framework. These simulations are used to determine whether the predefined architectural decisions result in physically credible ventilation behaviour under representative and elevated internal heat generation.

The assessment addresses the following validation questions:

- Does the enclosure sustain continuous forced airflow under intended operating conditions?
- Do vent geometries function as effective flow boundaries rather than symbolic openings?
- Does internal airflow meaningfully interact with dominant heat-generating regions?
- Does ventilation behaviour remain coherent under elevated thermal loading without structural instability or flow collapse?

The chapter does not attempt to optimise airflow performance, establish certified thermal margins, or predict component-level temperatures. Results are framed as behavioural validation outcomes supporting engineering judgement under constrained architectural conditions.

7.2 Component Definition and Boundary Conditions

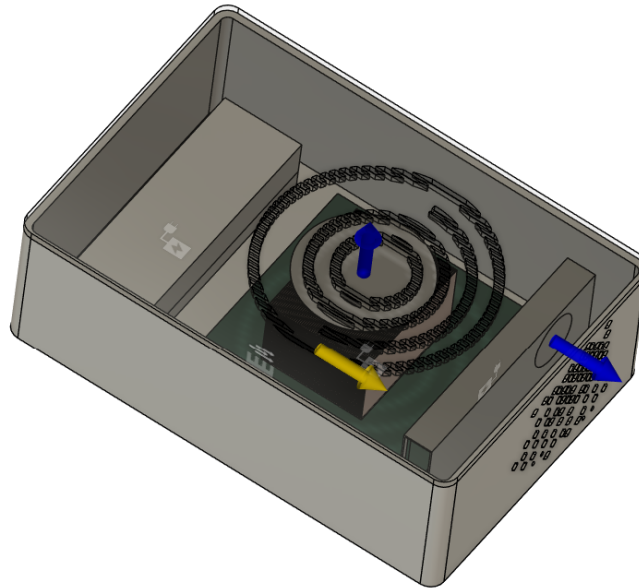


Figure 7.1: CFD Model Domain and Boundary Conditions.

The airflow and thermal assessment is grounded in a component-realistic system definition derived from commercially available hardware. Boundary condition values are taken directly from manufacturer datasheets and applied consistently across simulation cases.

Primary Processing Platform

Motherboard: ASUS ROG Strix B650E-I Gaming WiFi (Mini-ITX)

Processor: AMD Ryzen 9 7900 (12 cores, 3.7 GHz base clock, 64 MB L3 cache)

The processor constitutes the dominant internal heat source during operation.

Primary Cooling Assembly

CPU Cooler: Noctua NH-L9x65 chromax.black

Nominal airflow: approximately 33.84 CFM

This fan is modelled as the primary forced-convection driver within the enclosure.

Secondary Processing and Cooling

Graphics Card: NVIDIA A1000 single-slot professional GPU

Secondary blower airflow: approximately 3.5 CFM

The GPU fan contributes localised airflow support but does not govern global ventilation behaviour.

Power Delivery

Power Supply: HDPLEX 250 W GaN Passive AIO ATX PSU

The power supply is modelled as a passive thermal contributor with no active airflow

generation.

Consolidated Auxiliary Heat Sources

Memory modules, VRM circuitry, storage devices, and auxiliary electronics are represented as a consolidated motherboard heat load rather than discrete sources. This modelling decision reflects both their comparatively lower thermal output and the architectural scope of the study.

Thermal Loading Conditions (Fusion Electronics Cooling)

Two load regimes were applied:

Standard Working Load:

Dominant heat source: representative processor operating power

Secondary distributed loads: auxiliary electronics

Total internal heat generation: consistent with intended operating configuration

Elevated (Extreme) Load:

Discrete loads applied: 14 W + 50 W + 140 W

Total internal heat input: approximately 204 W

Ambient temperature in all thermal simulations was fixed at 25 °C.

ANSYS Fluent Cross-Verification Conditions

The ANSYS Fluent study was restricted to airflow topology verification and did not include internal heat generation.

Two actuation configurations were examined:

- Primary fan active (33.84 CFM), secondary fan inactive
- Both fans active (33.84 CFM and 3.5 CFM), including opposing-flow interaction case

No imposed external pressure gradients were applied. The enclosure was treated as nominally sealed, with all exchange occurring through defined vent geometries.

7.3 Ventilation Architecture and Modelling Assumptions

Ventilation is achieved through distributed vent geometries located on the top surface and side walls. These openings constitute the sole fluid communication between internal and external domains.

Fans were modelled at constant nominal airflow rates rather than full pressure-dependent fan curves. For the architectural scope of this study, constant volumetric flow modelling is acceptable because the objective is to verify global ventilation architecture and flow topology, not to predict exact operating-point performance. Given the moderate static pressure levels observed (order of tens of Pascals), the operating regime remains within the near-linear region of typical small axial fan pressure–flow characteristics. Therefore,

constant CFM modelling provides a reasonable first-order approximation for evaluating enclosure-level airflow organisation without materially altering qualitative behaviour.

Gravity was included to allow buoyancy effects to emerge naturally, although ventilation conceptually relies on forced convection rather than natural convection.

No assumptions were made regarding leakage paths, dust accumulation, fan degradation, or material ageing.

The computational methodology follows standard finite-volume discretisation principles for incompressible internal forced convection problems. Spatial discretisation and pressure–velocity coupling are consistent with conventional CFD formulations widely documented in foundational texts such as [35] and [36]. The intent is not methodological novelty but correct application of established numerical practice to the defined enclosure geometry.

7.4 Behaviour Under Standard Working Thermal Load

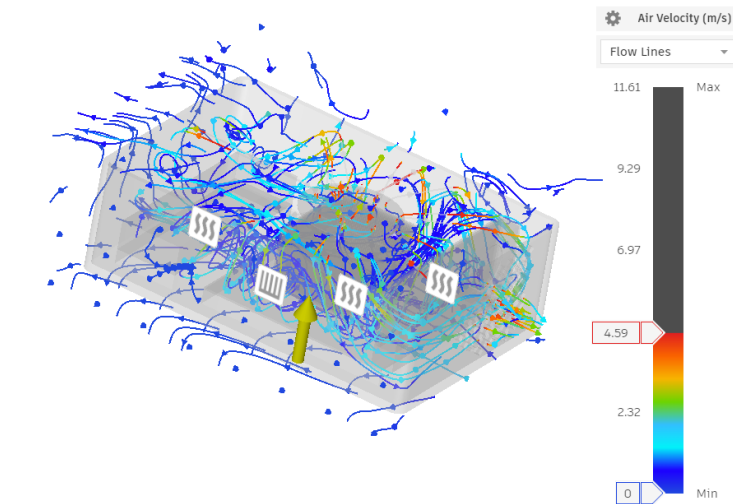


Figure 7.2: Internal Airflow Velocity Field (Standard Load).

Under standard working load, the enclosure exhibits continuous and organised forced airflow throughout its internal volume.

Velocity Field

Internal air velocities predominantly fall within the range of approximately 0.5 m/s to 4.7 m/s, with peak magnitudes occurring near the primary fan discharge region. These magnitudes are consistent with nominal 30–35 CFM axial fan operation within compact enclosures.

Velocity redistribution extends longitudinally across the enclosure volume, confirming that airflow does not remain confined to the immediate vicinity of the heat sink. Localised recirculation zones are observed near geometric transitions and enclosure walls. However, no regions of near-zero velocity or complete stagnation are detected at the resolution of the model.

7.5 Behaviour Under Elevated (Extreme) Thermal Load

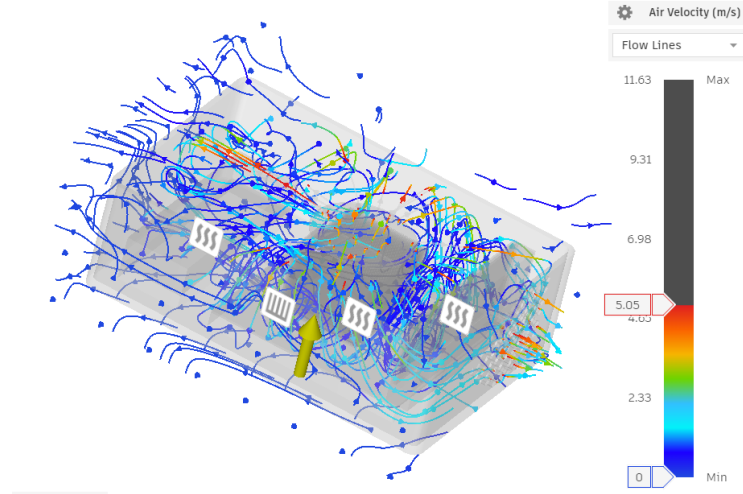


Figure 7.3: Airflow Velocity Field (Elevated Load).

Under elevated internal heat input of approximately 204 W, the enclosure retains its fundamental airflow organisation.

Velocity and Flow Topology

Peak velocity magnitudes remain within similar order-of-magnitude ranges as the standard case (up to approximately 4.5–4.7 m/s), indicating that fan-driven convection remains the dominant transport mechanism.

Recirculation intensity increases, particularly downstream of the dominant heat source. However, these recirculation structures remain dynamically coupled to primary flow paths and do not develop into isolated stagnant cavities.

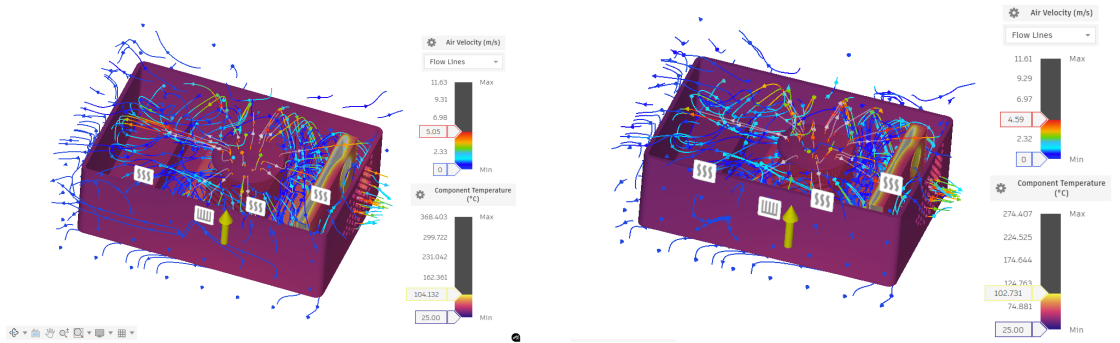


Figure 7.4: Comparative thermal response comparing (a) standard load and (b) elevated load.

7.6 Comparative Robustness and Cross-Verification Summary

Comparison between standard and elevated load cases indicates that increased thermal input amplifies gradients and recirculation complexity but does not alter the fundamental

airflow topology.

Independent airflow simulations conducted in ANSYS Fluent reproduce the same global ventilation logic. Under both single-fan and dual-fan actuation configurations, airflow remains distributed across the enclosure volume, and vent openings maintain active participation.

Across both computational environments:

- Internal velocities remain within physically reasonable magnitudes for the defined fan capacities.
- Pressure gradients remain coherent and bounded.
- Vent geometry functions as an effective exchange boundary.
- No enclosure-wide stagnation or non-physical behaviour emerges.

These observations confirm that ventilation behaviour is governed primarily by enclosure geometry and fan placement rather than solver-specific artefacts.

7.7 Limitations of the Airflow and Ventilation Assessment

The assessment does not constitute a comprehensive thermal performance evaluation.

Limitations include:

- Constant fan flow rates (no full fan-curve modelling)
- Consolidated auxiliary heat modelling
- Absence of leakage modelling
- No dust or blockage simulation
- No long-term material ageing considerations

ANSYS Fluent study restricted to airflow topology only (no thermal modelling)

Within these bounds, the assessment verifies physical plausibility, architectural coherence, and ventilation robustness under representative and exaggerated internal loading conditions.

08

Risk and Reliability Assessment of the Validated Configuration

This chapter examines reliability as an emergent property of fixed geometry, material assumptions, manufacturing constraints, and interface definition under industrial exposure. It applies DFMEA-based reasoning to identify risk concentration zones and to interpret configuration-level robustness without probabilistic lifetime prediction.

Chapter 8

Risk And Reliability Assessment Of The Validated Configuration

8.1 Reliability Context And Validation Responsibility

In this thesis, reliability is addressed as a validation responsibility rather than as a downstream certification exercise or a design optimisation objective [27]. The enclosure is evaluated as a machine-mounted artefact operating in an industrial environment characterised by sustained vibration, airborne contaminants, thermal cycling, and continuous operation, where reliability emerges from the interaction between geometry, material properties, manufacturing constraints, and interface definition [27, 4].

Rather than attempting to predict lifetime metrics or probabilistic failure rates, reliability is examined through the identification and validation of credible failure mechanisms associated with the fixed enclosure configuration [27]. This approach reflects common industrial practice, where early-stage engineering validation focuses on excluding physically adverse conditions and confirming robustness under representative loading rather than pursuing exhaustive statistical qualification [4].

Numerical analysis is therefore employed as a confirmatory tool to assess the plausibility of enclosure behaviour at critical interfaces, not as a means of redefining architecture, materials, or assembly logic [20, 18].

8.2 Critical Interfaces And Risk Concentration Zones

Reliability-related risks within the enclosure are not uniformly distributed, but concentrate at interfaces where mechanical loads, environmental exposure, or repeated interaction occur [18]. Identifying these risk concentration zones is fundamental to evaluating long-term robustness in machine-adjacent industrial equipment [27, 18].

The primary mechanical interface is the rear DIN rail mounting system, where self-weight and operational loads are transferred into the supporting machine structure. This interface is subject to sustained loading and structure-borne vibration, making it a critical zone for

Risk-Assessment Matrix

Severity	Probability (expected frequency)				
	Frequent Regular events	Likely Several events	Occasional Sporadic events	Seldom Infrequent events	Unlikely Improbable events
Catastrophic Unacceptable loss	Very High	High	High	High	High
Critical Severe loss	High	Medium	Medium	Medium	Medium
Moderate Minor loss	Medium	Medium	Medium	Medium	Medium
Negligible Minimal loss	Medium	Medium	Medium	Medium	Medium

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Figure 8.1: Reliability Context and Interface Risk Map.

retention stability and load-path integrity [18, 4].

Fastener interfaces represent another significant concentration of risk. Threaded bosses experience localised stresses during tightening and are sensitive to vibration-induced loosening, preload loss, and fatigue-related degradation [29, 4]. Their geometry, engagement length, and surrounding material stiffness directly influence reliability under service conditions.

The front panel interface constitutes a combined mechanical and environmental boundary. This region must preserve alignment under repeated opening and closing while maintaining controlled separation between the internal volume and the surrounding environment. Surface flatness consistency and preload retention therefore represent critical reliability factors [18].

Additional risk concentration zones include ventilation openings, where material removal locally reduces stiffness, and panel-mounted interfaces such as the power inlet and power switch, which combine mechanical fixation with user interaction and cable-induced loading [29].

8.3 Risk Identification Across Manufacturing, Assembly, And Use

Risk identification is performed across the full lifecycle of the enclosure, encompassing manufacturing, assembly, installation, operation, service, and handling. Rather than treating risks as abstract events, they are identified in direct relation to physical interfaces, load introduction points, and environmental exposure conditions inherent to the validated configuration [27, 18].

Manufacturing-related risks include tolerance accumulation at critical interfaces, surface integrity degradation at machined features, and localised compliance arising from slender geometries or insufficient section thickness [29, 25]. Assembly-related risks arise from fastener tightening, uneven torque distribution, cable routing freedom, and handling-

induced loading during integration and service [18].

Use-related risks include sustained vibration transmitted through the machine structure, thermal cycling associated with continuous operation, airborne contaminants typical of industrial environments, and repeated interaction with user-facing interfaces [4, 8]. These risks are not considered in isolation, but as interacting influences capable of activating failure mechanisms at specific regions of the enclosure over time.

8.4 Anticipated Failure Modes And Effects (DFMEA Perspective)

Table 8.1
Configuration-Level DFMEA Summary

DFMEA Table

Item / Function	Failure Mode	Effects	S	Causes	O	Current Controls (Final Configuration)	D	RPN	Mitigation Strategy	Implemented Measure	Target (S/O/D → RPN)
DIN-rail mounting interface	Loss of retention	Detachment, misalignment, downtime	9	Vibration; incomplete engagement	5	Dedicated rear bracket; mounting treated as fixed structural boundary	7	315	Constrain rail geometry; secondary retention; engagement verification	-	9/3/4 → 108
Mounting / bracket fasteners	Preload loss	Rattle; fatigue initiation	7	Sustained vibration	6	Locally thickened fastening regions; monolithic load path	7	294	Controlled torque and defined locking method	Locking washers + torque specification (≥85–90% preload retention)	7/4/4 → 112
Threaded bosses (AI 7075)	Thread stripping	Loss of clamping	6	Over-torque; insufficient engagement	5	Integrated boss geometry; local thickening; 7075 stiffness	5	150	Minimum engagement rule (≥1–1.5D); torque control	-	6/3/3 → 54
Front panel perimeter (micro-milled Al-AI)	Local gap formation	Uncontrolled ingress	7	Tolerance stack; seating irregularity	5	Precision-machined mating surfaces; deterministic seating	7	245	Controlled flatness and finish; eliminate gasket dependency	≤0.01 mm flatness; Ra ≤0.4 µm; sharp-edge contact	7/3/4 → 84
Vent openings	Blockage by contaminants	Airflow reduction; hotspot risk	8	Chip/oil accumulation	6	Ventilation verified under fixed geometry	9	432	Geometry-led ingress control; inspection provision	Stepped internal pathway; no direct line-of-sight ingress	8/4/6 → 192
GPU support	Support loosening	PCle stress; intermittent fault	8	Vibration-induced preload loss	5	Mechanical decoupling of connector loads	7	280	Positive-lock geometry; torque verification	Rear machined support wall transferring cantilever loads	8/3/4 → 96
Power inlet (IEC C14)	Connector loosening	Power interruption; arcing risk	10	Cable strain; vibration	3	Reinforced panel interface	6	180	Strain relief and controlled cut-out fit	Constrained seating via aligned M3 countersunk pockets	10/2/3 → 60
Power switch (22 mm)	Rotation / loosening	Control unreliability	6	Repeated interaction; vibration	4	Flush-mount boundary interface	5	120	Anti-rotation feature; torque control	Self-locking M22 nut with friction-enhanced interface	6/3/3 → 54
Mounting plane geometry	Warpage	Poor DIN engagement	7	Machining distortion	3	Tolerance localisation; functional datum strategy	6	126	Defined datum hierarchy; flatness control	±0.01 mm verified seating deviation	7/2/4 → 56
Surface condition (AI 7075)	Corrosion / oxidation	Long-term degradation	5	Humidity; oil mist	6	As-machined baseline	9	270	Conditional surface treatment	Type II anodization (10–25 µm)	5/4/6 → 120
Handling / installation loads	Local denting	Misfit; airflow restriction	4	Impact during handling	4	Structural stiffness validated under top-load case	6	96	Handling notes; packaging constraint	-	4/3/4 → 48

Using Design Failure Mode and Effects Analysis (DFMEA) reasoning as an analytical lens, anticipated failure modes are identified by examining how the previously defined risks may manifest at critical interfaces under representative operating conditions [18]. The DFMEA is employed here not as a compliance-oriented risk management exercise, but as a structured method for mapping credible failure mechanisms to their physical effects within a fixed enclosure configuration.

Severity (S), Occurrence (O), and Detection (D) ratings are assigned using project-specific qualitative scales aligned with machine-adjacent industrial equipment rather than consumer electronics. Severity ratings reflect system-level functional consequences rather than probability of occurrence, while Occurrence and Detection are estimated based on engineering judgement informed by the operating environment, assembly logic, and accessibility of interfaces.

Risk Priority Numbers (RPN) are calculated as the product of Severity, Occurrence, and Detection ($RPN = S \times O \times D$) and are used solely as a relative prioritisation tool. Known limitations of multiplicative RPN scoring are acknowledged; however, within a single-system DFMEA using consistent rating criteria, RPN effectively highlights concentrations of risk and supports structured mitigation reasoning [18, 20]. RPN values are therefore not interpreted as absolute measures of risk acceptability.

09

Assembly, Installation, and Maintainability

This chapter verifies that the validated enclosure architecture remains assemblable, installable, and serviceable under representative industrial interaction scenarios. It confirms consistency between analytical validation outcomes and real-world assembly, DIN rail installation, wiring accommodation, and maintenance practices.

Chapter 9

Assembly, Installation, And Maintainability

9.1 Assembly Sequence And Procedural Assumptions

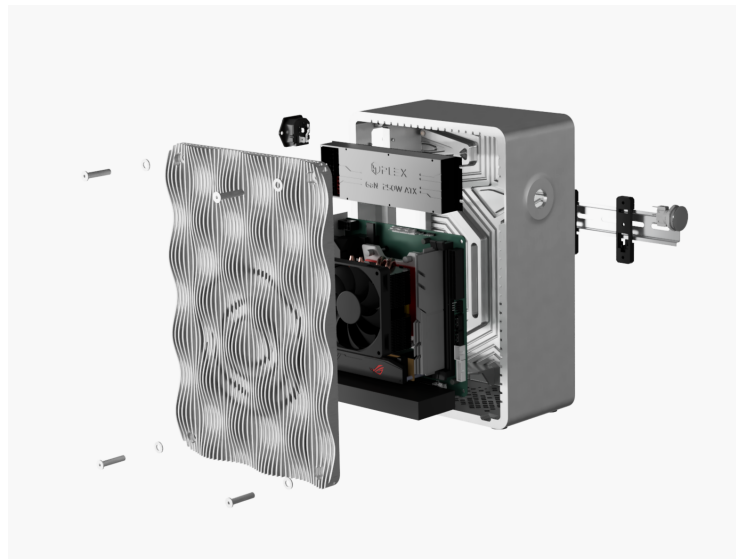


Figure 9.1: Assembly Sequence Overview

Assembly considerations in this thesis are addressed not as a design activity, but as a verification that the validated enclosure architecture can be realistically assembled under representative industrial conditions [18, 23]. The enclosure is assumed to be assembled manually in low-volume or prototype-oriented contexts typical of laboratory validation, commissioning, and early-stage industrial deployment [23].

Assembly operations are intentionally limited in tool variety and fastener count, relying on standard hand tools and a small number of fasteners to achieve full enclosure closure and internal integration. This assumption reflects established industrial assembly practice and avoids dependence on specialised fixtures or process controls that would invalidate subsequent handling and service assessments [18, 23].

Assembly is assumed to proceed from the internal system outward, a sequence that minimises manipulation within confined volumes and reduces the likelihood of connector damage, misalignment, or assembly-induced stress [18]. The motherboard is installed first, establishing the primary spatial and functional reference within the enclosure. Processor, memory, and storage components are mounted prior to enclosure insertion, reducing internal handling and preserving access to mounting features.

The power supply and graphics card are subsequently installed as discrete sub-assemblies. Treating these elements as independent modules limits interference with cable routing and preserves access to fastening interfaces, while mechanical support is assumed to decouple connector loads from handling and vibration effects [23].

Electrical interfaces such as the power inlet and user control switch are installed through direct mechanical retention at their respective enclosure interfaces. These operations are assumed to occur prior to final closure to ensure accessibility for wiring and strain relief, while enclosure closure is achieved through front-accessible fasteners establishing preload-defined aluminium-to-aluminium perimeter contact. No adhesives, permanent deformation, or concealed retention features are assumed [23].

DIN rail mounting hardware is treated as an optional installation accessory rather than an intrinsic structural element. This assumption allows the device to be evaluated, commissioned, or serviced off-machine without unnecessary constraints, while preserving compatibility with machine-mounted deployment when required [11].

9.2 Installation Onto Machine Structures

Installation onto the machine is achieved by mounting the fully assembled enclosure onto a vertical DIN rail via a dedicated rear interface. The device is handled and installed as a complete unit, without requiring partial disassembly or access to internal components, preserving enclosure integrity during installation and reducing the risk of contamination or handling damage [11].

The mounting interface is assumed to permit full removal of the enclosure from the DIN rail when required, enabling relocation, replacement, or off-machine service. Installation and removal are reversible operations relying on standardised DIN rail engagement rather than bespoke fastening procedures [11].

By decoupling installation from internal access, the enclosures interaction with the machine is confined to the rear mounting interface, while all functional, service, and validation-relevant interactions remain concentrated at the front face. This separation ensures that machine installation does not constrain service operations or invalidate previously assessed internal clearances and airflow paths [12].



Figure 9.2: Installation View.

9.3 Wiring Accommodation And Preservation Of Validated Airflow Paths

Internal wiring is treated as a volumetric and spatial requirement rather than as a fixed routing prescription. Given variability in cable stiffness, connector geometry, and assembly practice, rigid routing channels are avoided, as they would represent idealised CAD conditions rather than realistic industrial assembly behaviour [13].

Instead, the enclosure is assumed to provide sufficient internal clearance to accommodate pragmatic cable routing, slack management, and secondary fixation using common industrial methods. This approach allows wiring to be adapted during assembly or maintenance without introducing geometric interference or forcing cable paths that could compromise accessibility [23, 13].

By avoiding dense or prescriptive routing features, the airflow paths previously assessed during ventilation verification are preserved under realistic wiring conditions. Cable management is therefore evaluated implicitly as part of airflow robustness rather than as an independent design objective [23, 13].

9.4 Service Access And Maintainability Considerations

Service access is assumed to occur primarily through the front interface, which acts as the sole required access point for internal maintenance operations. All fasteners required to open the enclosure are front-accessible, allowing panel removal without specialised tools or access to secondary surfaces [23, 18].

While enclosure opening is mechanically possible with the device mounted on the DIN rail, the preferred service condition is assumed to involve removal of the unit from the rail



Figure 9.3: Service Access Envelope

prior to opening. In this configuration, the enclosure can be placed on a horizontal surface, improving stability and handling safety during component replacement. This assumption reflects accepted ergonomic and safety practice rather than a geometric constraint [12].

Internal components including memory, storage, graphics card, power supply, and panel-mounted interfaces are assumed to be replaceable without permanent deformation, adhesive bonding, or destructive operations. Maintenance is therefore treated as a repeatable activity compatible with multiple service cycles, consistent with industrial expectations for machine-adjacent equipment [23].

Environmental separation during operation is achieved through controlled surface flatness and distributed fastener preload rather than full enclosure sealing. Controlled metal-to-metal perimeter contact limits uncontrolled ingress at the panel joint while preserving deliberate airflow through vented regions. Maintenance is assumed to occur under typical shop-floor conditions rather than clean-room environments, reflecting realistic industrial service practices.

9.5 Closing Note

This chapter does not introduce new design decisions, but verifies that the validated enclosure architecture remains assemblable, installable, and serviceable under representative industrial interaction scenarios. By explicitly addressing assembly, installation, and maintenance as post-validation realities, the chapter reinforces the physical credibility of the enclosure as a machine-integrated artefact and ensures consistency between analytical validation and real-world use [18, 23].

10

Technical Definition and Validated Configuration

This chapter consolidates the bill of materials, technical drawings, and dimensional specification logic defining the validated reference configuration. It formalises the enclosure as a frozen technical baseline linking architectural assumptions to manufacturing, assembly, and installation documentation.

Chapter 10

Technical Definition and Validated Configuration

10.1 Bill of Materials as Configuration Boundary

The complete bill of materials is provided in Appendix B and constitutes the hierarchical system definition of the validated artefact. Rather than serving merely as a procurement list, the BOM formalizes the boundary between custom-manufactured structure, standardized commercial components, and installation hardware.

Monolithic structural elements are explicitly identified as CNC-milled Aluminium 7075 components, while electronic subsystems, fastening elements, and boundary interfaces are specified by manufacturer and commercial reference. This distinction reflects the methodological stance of the thesis: geometry and load paths are architecturally defined, while electronic modules are treated as fixed boundary conditions.

Material class, manufacturing process, and assembly level are declared for each line item to ensure reproducibility and traceability. The BOM therefore operates as a configuration lock, establishing the validated system state against which all structural, thermal, and risk assessments are grounded.

10.2 Drawing Set as Authoritative Geometric Definition

The complete technical drawing set is provided in Appendix A and constitutes the authoritative geometric and dimensional definition of the validated configuration. The drawings do not illustrate a conceptual proposal; they define a manufacturable and inspectable artefact.

Dimensional specification is applied selectively. Tight tolerances are assigned only to interfaces governing installation, structural load transfer, mating stability, and environmental control. Functional surfaces are explicitly controlled through flatness, profile, and surface finish requirements, while non-critical volumes retain relaxed tolerances to preserve manufacturing feasibility.

Datum hierarchies reflect installation logic rather than geometric symmetry. Primary

references are anchored to mounting and interface planes, ensuring that inspection aligns with functional reality. Thread classes, engagement depths, and surface conditions are specified where structural or service reliability depends upon them.

Surface finish prescriptions are restricted to functional interfaces. Where surface state does not influence assembly stability, airflow behaviour, or environmental robustness, finishes remain non-prescriptive. This selective approach prevents over-constraining the geometry while preserving repeatability at critical boundaries.

10.3 Specification Philosophy and Determinism

The drawing set reflects a determinism-oriented specification strategy. Mating faces are defined to prevent positional drift during assembly. Sharp-edge requirements and controlled seating geometries eliminate ambiguity in panel engagement. Fastening interfaces are dimensioned to preserve preload retention under vibration exposure.

Geometric controls are therefore not aesthetic constraints but reliability enablers. Flatness requirements, tolerance localisation, and datum strategy collectively ensure that validated airflow paths, structural load transfer routes, and service access clearances are not invalidated by manufacturing variation.

This approach transforms the enclosure from a geometric object into a controlled mechanical system whose performance assumptions are physically preserved through fabrication and assembly.

10.4 Validated Configuration Reference State

Appendix A and Appendix B together define the frozen reference configuration of the machine-integrated edge device. No further geometric iteration is assumed within the scope of this thesis.

The validated configuration integrates predefined electronic architecture within a monolithic structural enclosure, supports DIN-rail installation, preserves verified airflow topology, and distributes vibration loads through defined structural paths. Any future modification must be evaluated relative to this documented baseline.

10.5 Closing Statement

With the formalization of the bill of materials (Appendix B) and the authoritative drawing set (Appendix A), the artefact transitions from an object of investigation into a fully specified engineering reference system. The enclosure is no longer described conceptually; it is defined dimensionally, materially, and procedurally.

Appendix A and Appendix B therefore constitute the definitive technical baseline for manufacturing, inspection, installation, and subsequent industrial development.

11

Conclusions and Methodological Implications

This chapter summarises validation outcomes across mechanical, thermal, and procedural domains within declared boundary conditions. It articulates the methodological contribution, limitations, and final reference state of the enclosure as a defensible engineering baseline grounded in disciplined validation rather than optimisation.

Chapter 11

Conclusions and Methodological Implications

11.1 Summary of Validation Outcomes

This thesis presented a validation-oriented engineering investigation of a machine-integrated edge device enclosure intended for deployment in CNC machining environments. The enclosure architecture, material system, manufacturing strategy, installation logic, and electronic configuration were treated as fixed boundary conditions. Within these constraints, engineering analysis was employed as a plausibility filter rather than as a tool for optimisation.

Mechanical simulation demonstrated coherent load transfer under gravity-dominated and handling-related scenarios. Static deformation remained small relative to geometric scale, stress levels remained well below material yield, and modal analysis identified the first global natural frequency at 164.267 Hz, with subsequent modes at higher frequencies. No low-frequency structural softness or instability was observed under the defined mounting assumptions.

Airflow assessment confirmed organised internal flow behaviour under representative and elevated heat loads. Velocity and pressure distributions remained physically consistent, and no enclosure-wide stagnation or structural collapse of airflow was detected. Thermal behaviour aligned with the intended architecture without reliance on geometric modification.

Risk and robustness analysis identified critical interfaces and credible failure mechanisms across manufacturing, assembly, installation, and use. Monolithic load paths, local thickening at structural interfaces, and tolerance localisation collectively support mechanical stability under vibration and service conditions.

Across mechanical, thermal, and procedural domains, no physically adverse behaviour was identified within the declared boundary conditions.

11.2 Methodological Contribution

The primary contribution of this work lies in formalising a pragmatic validation framework aligned with industrial development constraints. Rather than pursuing optimisation, the thesis demonstrates how disciplined boundary definition, explicit modelling assumptions, and targeted simulation can exclude implausible behaviour and confirm structural and thermal coherence in a constraint-driven artefact.

The methodology integrates mechanical plausibility assessment, airflow verification, and structured risk reasoning into a unified validation approach suitable for machine-integrated hardware where architectural decisions are frequently locked early in development.

11.3 Limitations

The analyses were limited to linear elastic structural behaviour and simplified airflow modelling. Fatigue life prediction, stochastic vibration modelling, long-term environmental degradation, and regulatory certification were not addressed. Results apply strictly to the defined reference configuration under stated representative conditions.

11.4 Final Statement

Within its declared scope, this thesis establishes that the defined monolithic aluminium enclosure architecture behaves coherently under representative mechanical and thermal conditions. The artefact transitions from conceptual definition to technically specified reference system through disciplined validation rather than optimisation. The documented configuration provides a defensible engineering baseline for manufacturing, installation, and future industrial development.

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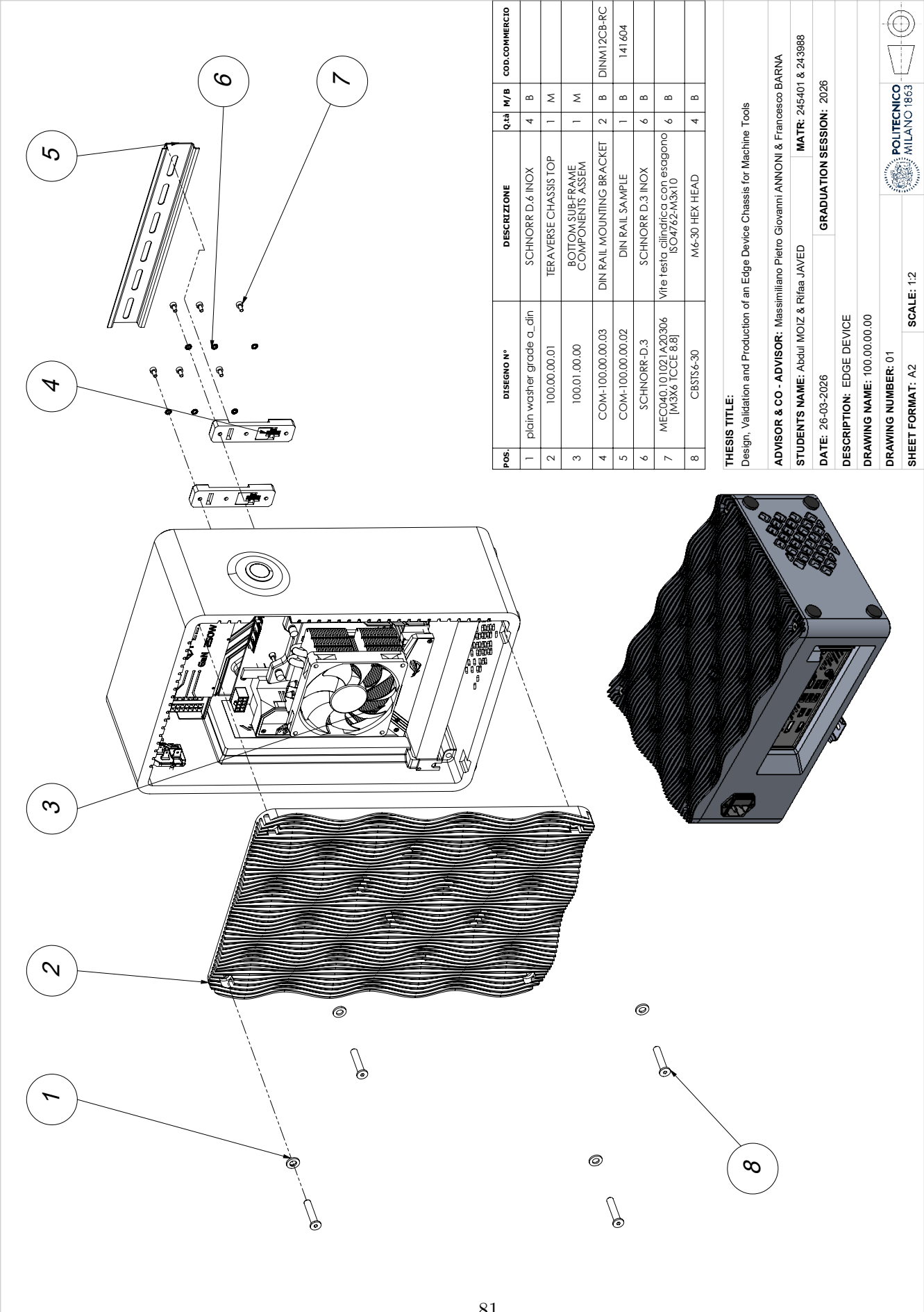
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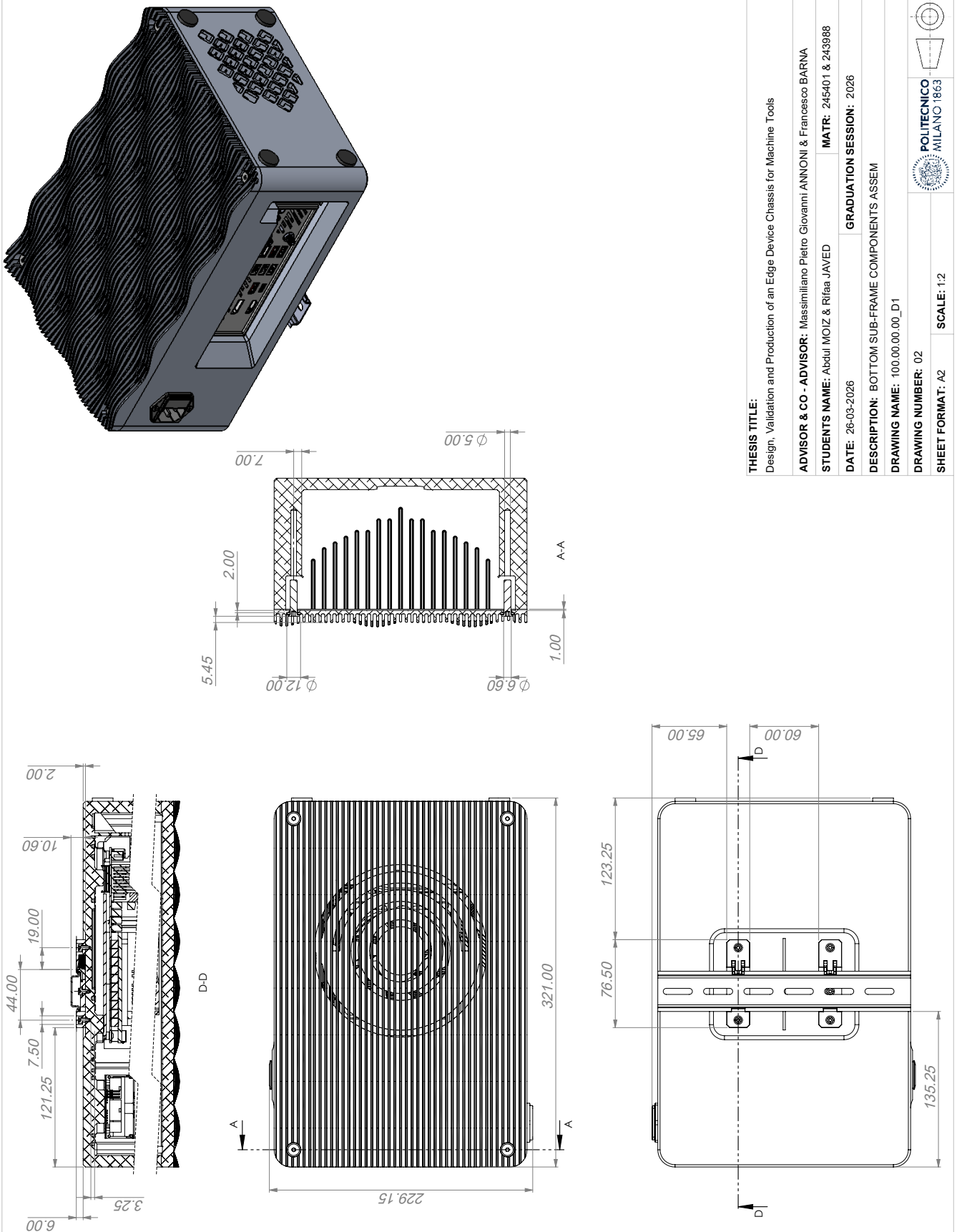
Appendix A

Detailed Manufacturing Drawings

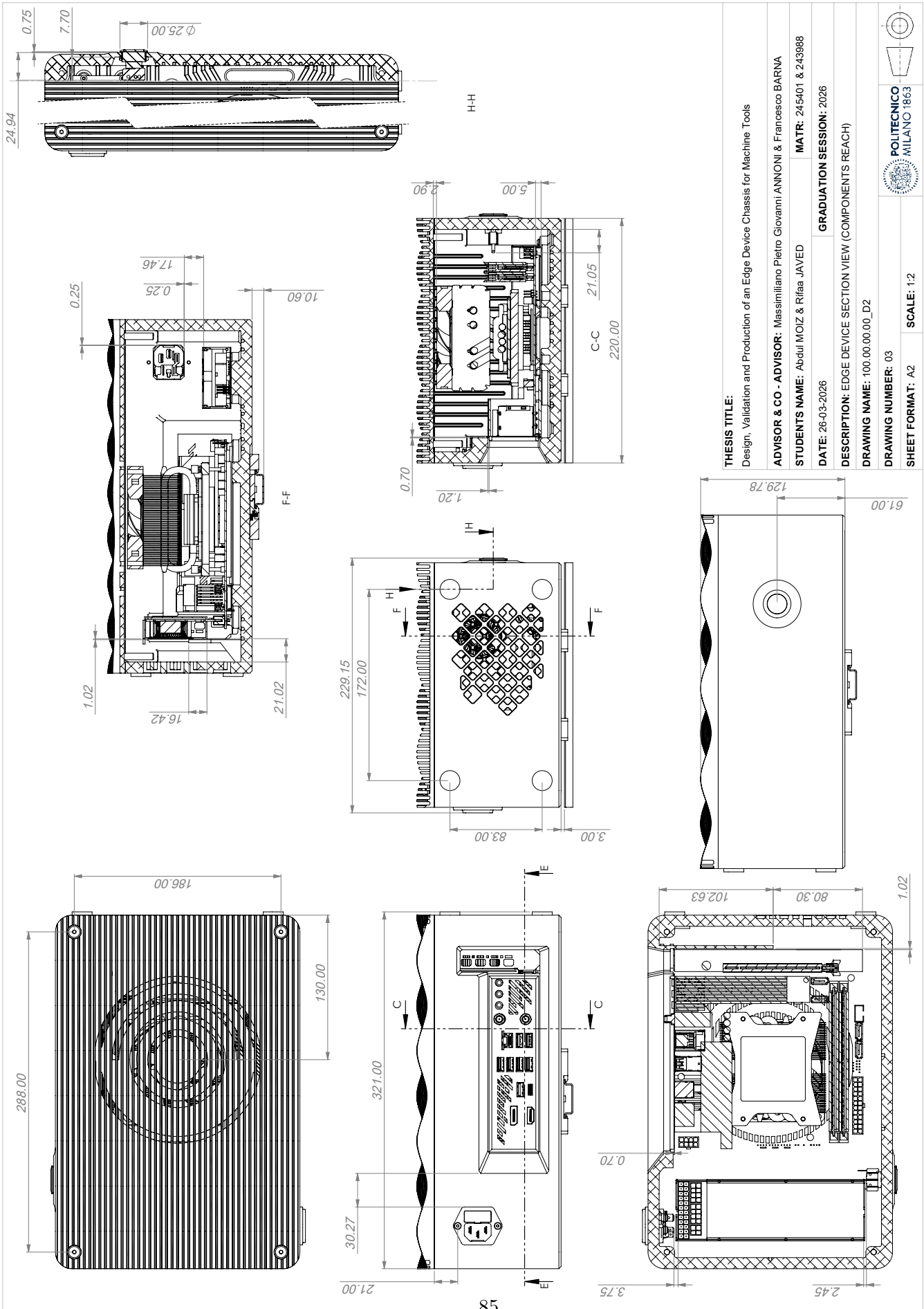
A.1 Edge Device



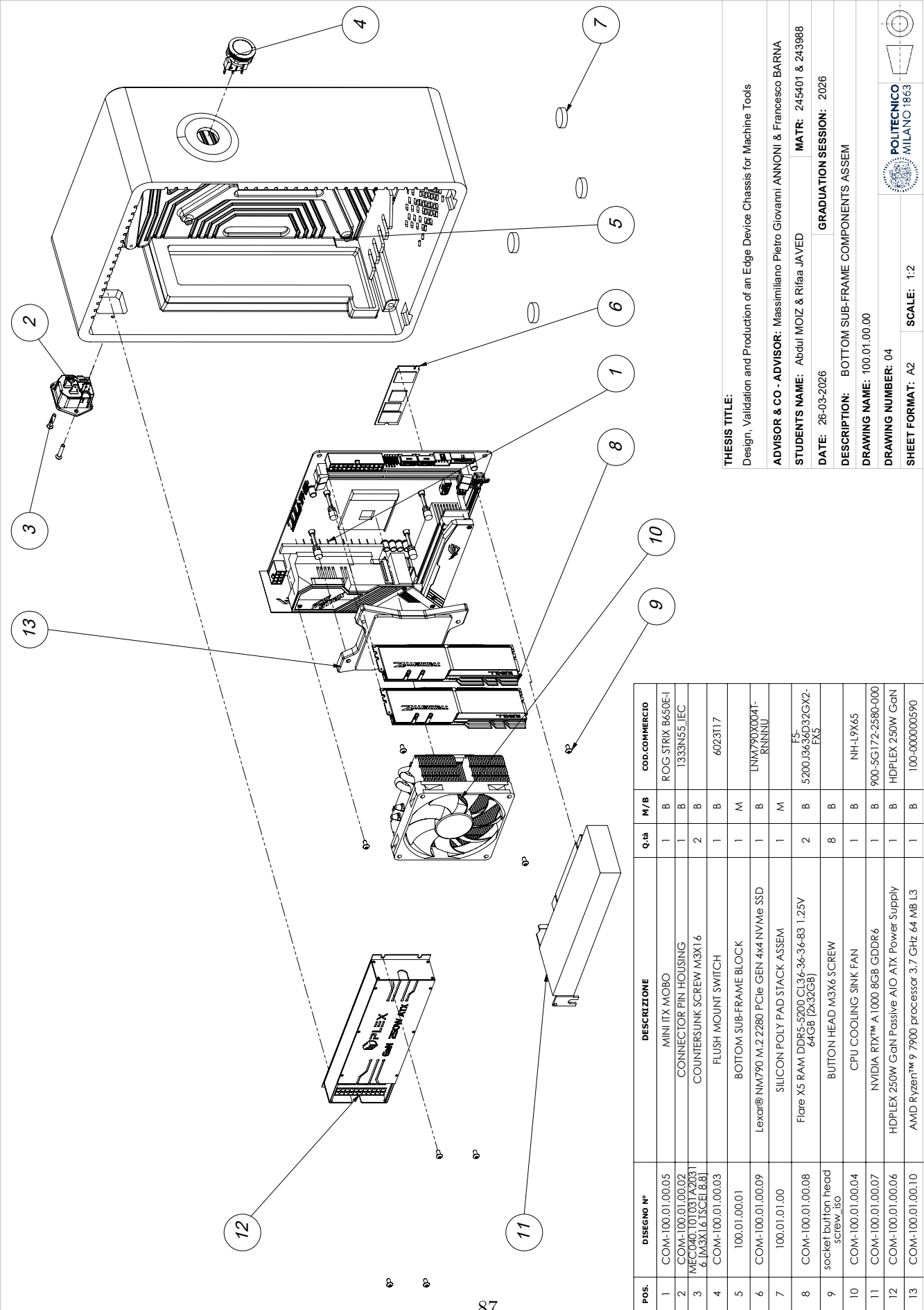
A.2 Bottom Sub-Frame Components Assembly



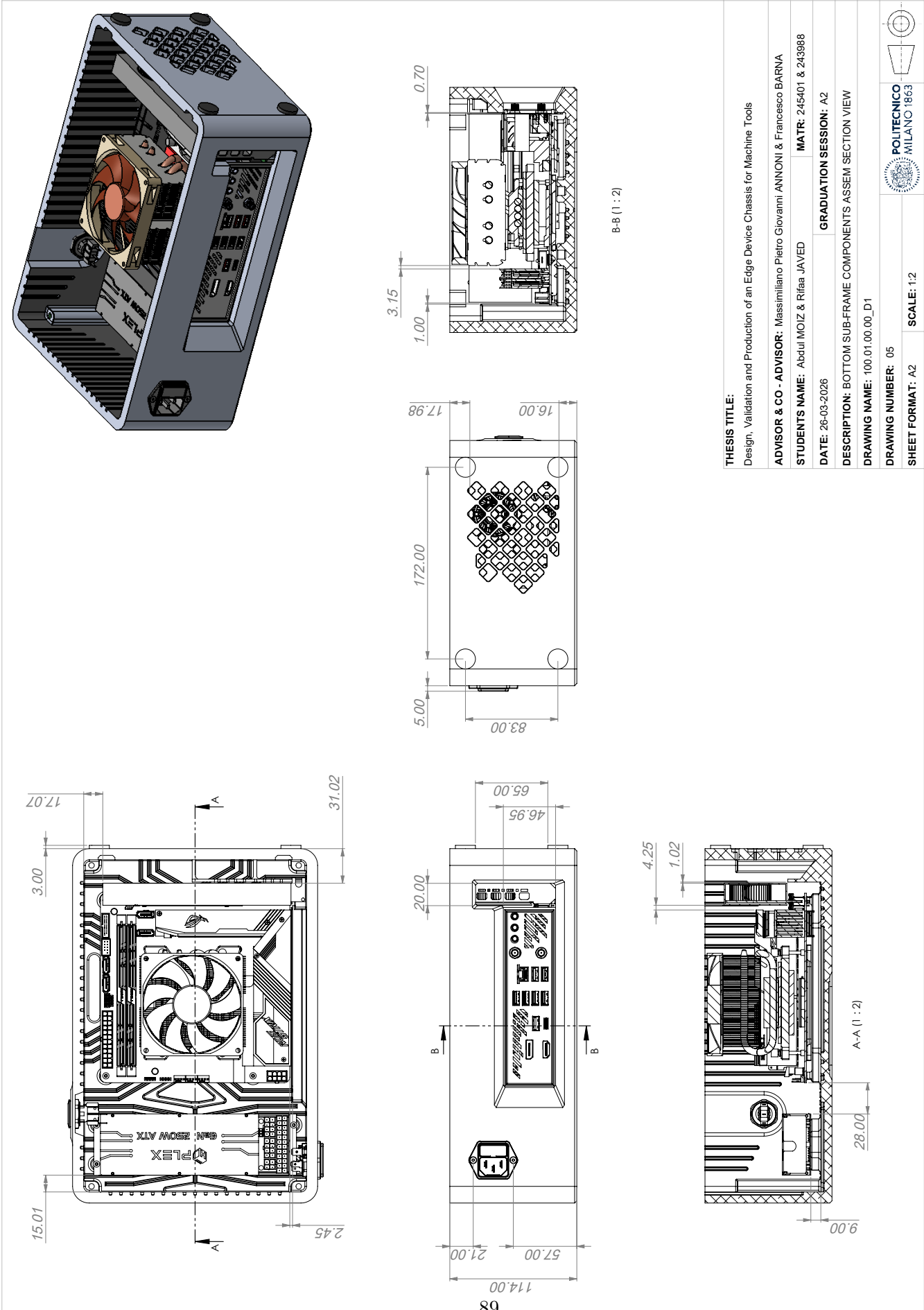
A.3 Edge Device Section View (Components Reach)



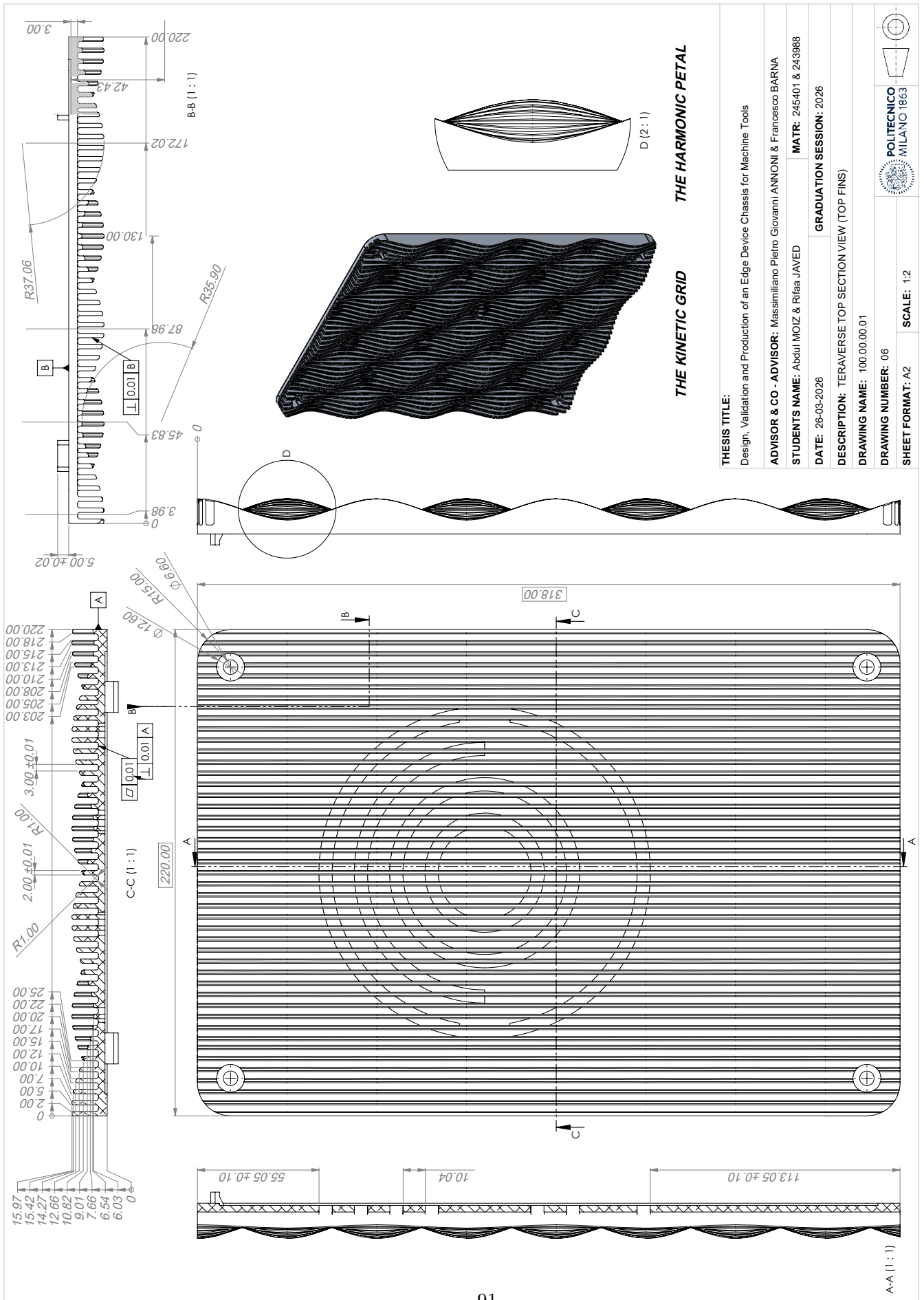
A.4 Bottom Sub-Frame Components Assembly



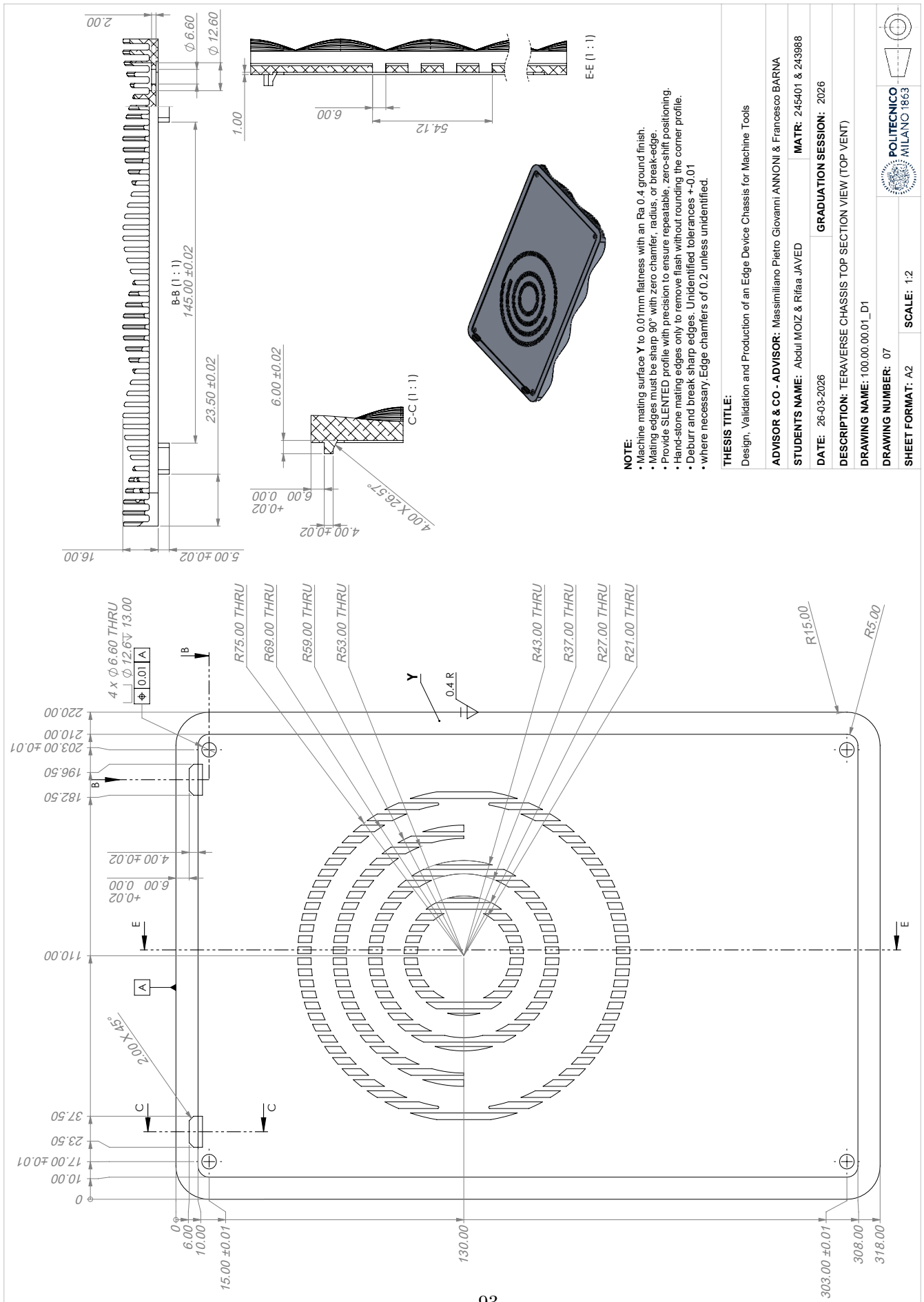
A.5 Bottom Sub-Frame Components Assembly Section View



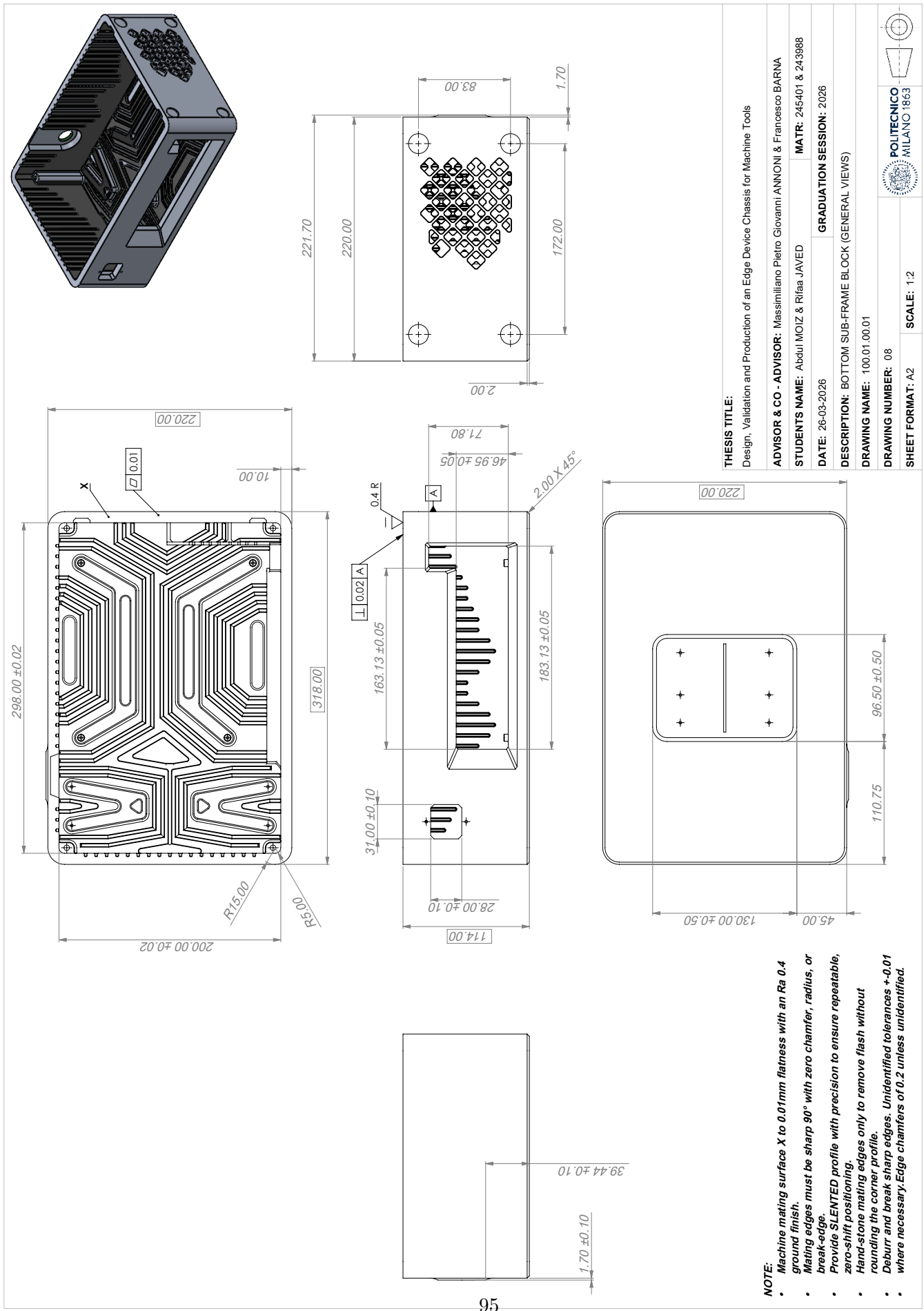
A.6 Teraverse Top Section View (Top Fins)



A.7 Teraverse Chassis Top Section View (Top Vent)



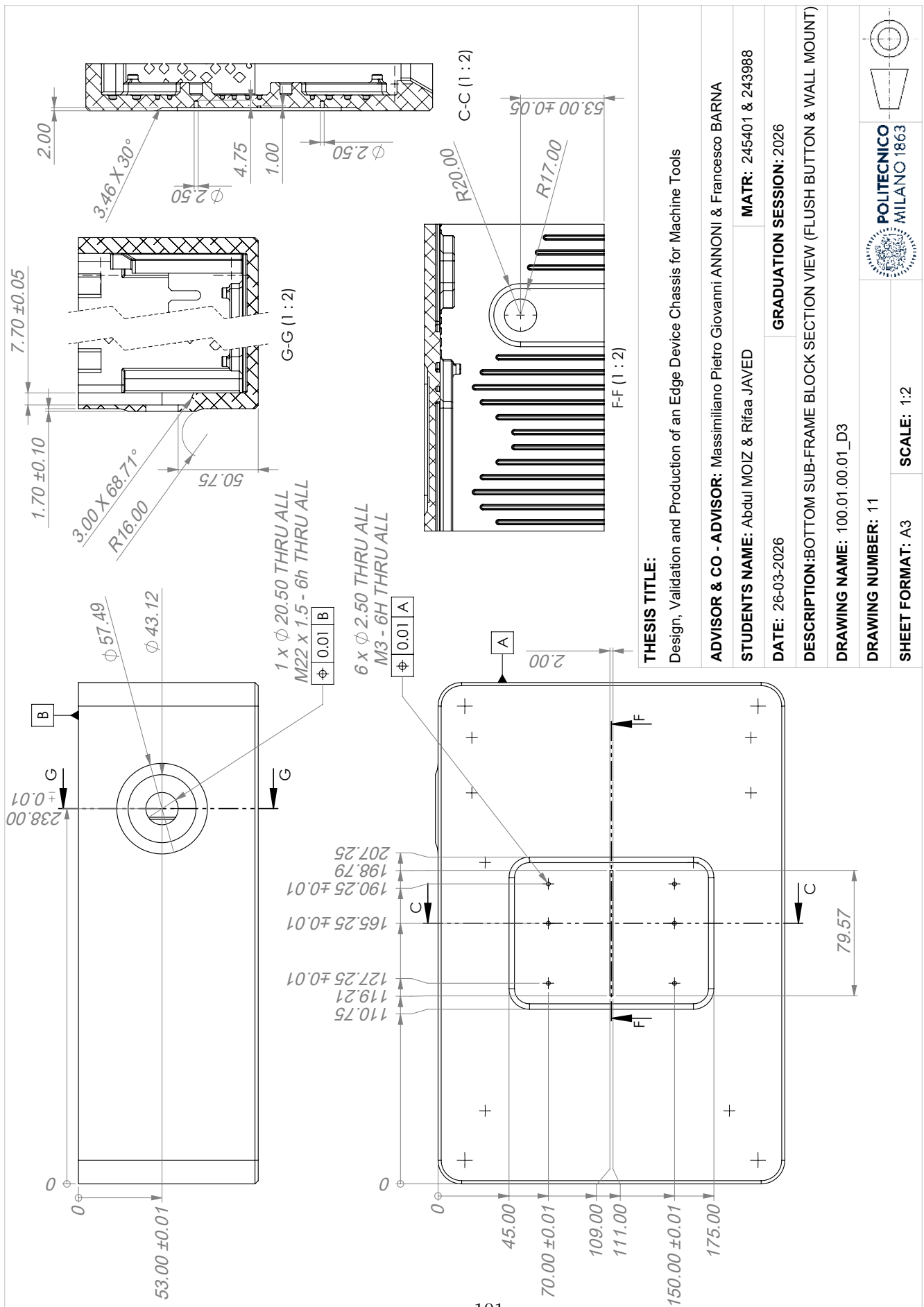
A.8 Bottom Sub-Frame Block (General Views)



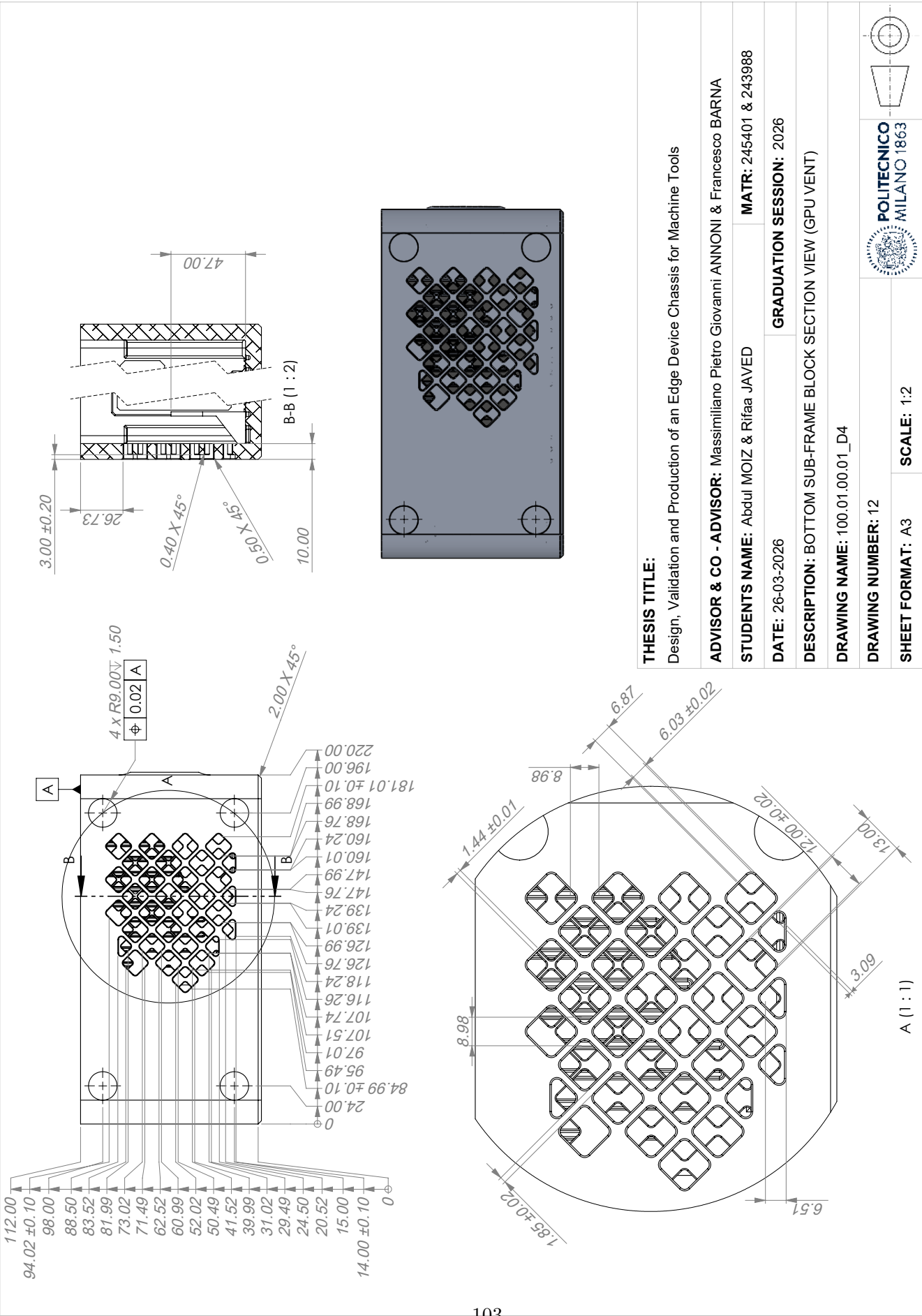
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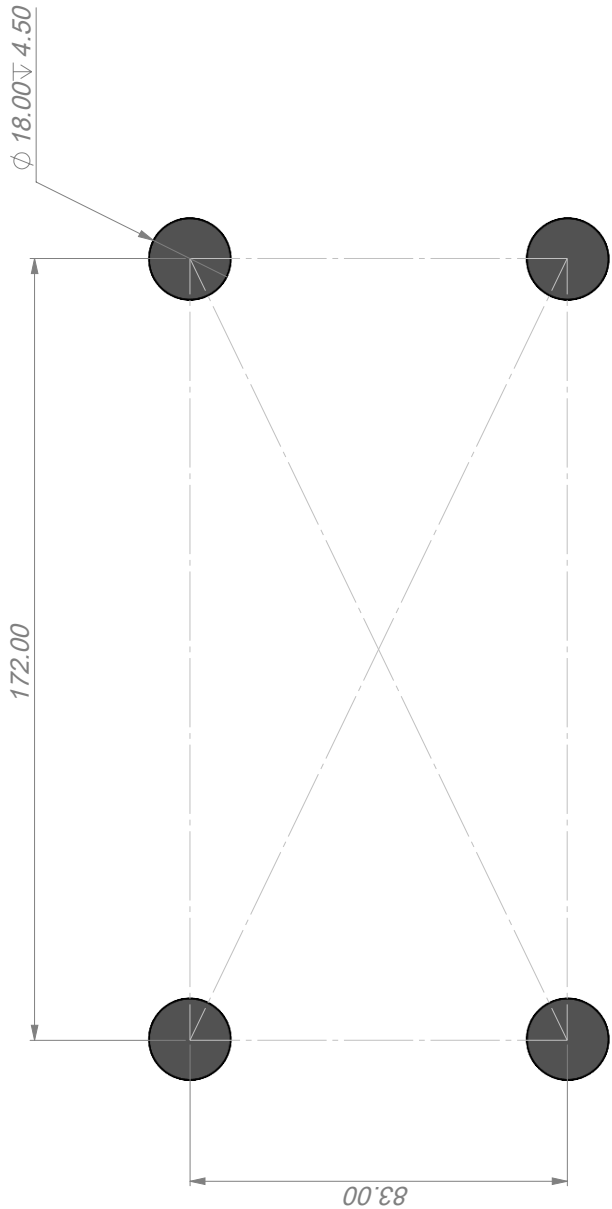
A.11 Bottom Sub-Frame (Flush Button & Wall Mount)



A.12 Bottom Sub-Frame (GPU Vent)



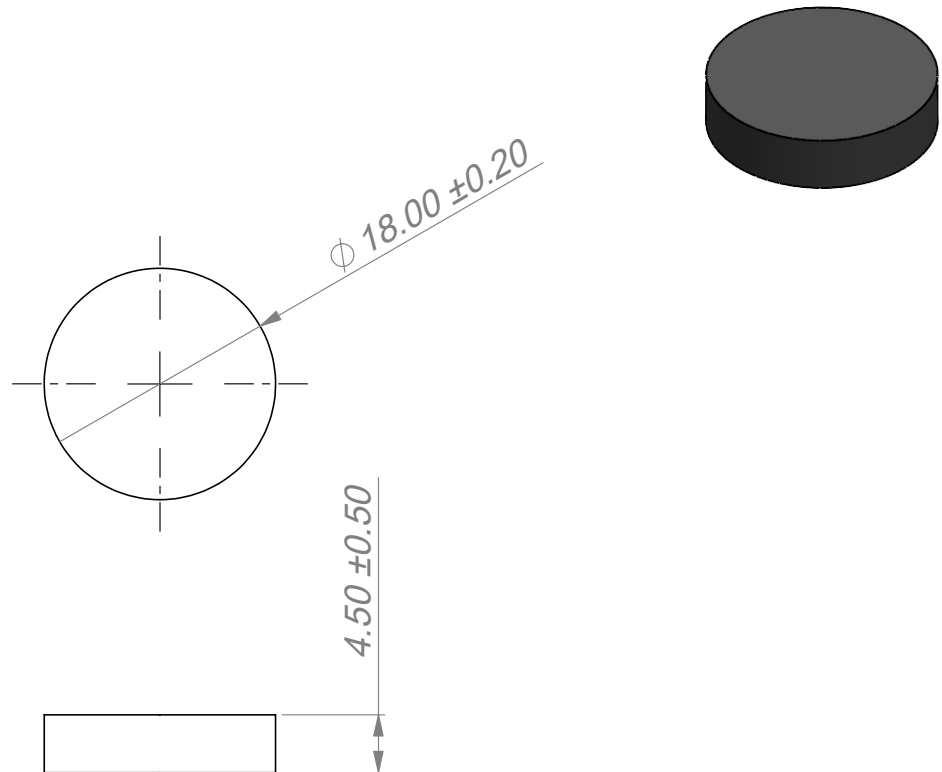
A.13 Silicon Pad Arrangement Footprint



- 1. SILICONE RUBBER, 60 SHORE A $\pm$ 5 ARRANGEMENT.
- 2. FOOTPRINT SKETCH TO BE DETERMINED FOR THE PREDEFINED PLACEMENT SUPPORT.

THESIS TITLE: Design, Validation and Production of an Edge Device Chassis for Machine Tools	
ADVISOR & CO - ADVISOR: Massimiliano Pietro Giovanni ANNONI & Francesco BARNA	
STUDENTS NAME: Abdul MOIZ & Rifaa JAVED	MATR: 245401 & 243988
DATE: 26-03-2026	GRADUATION SESSION: 2026
DESCRIPTION: SILICON PAD ARRANGEMENT FOOTPRINT	
DRAWING NAME: 100.01.01.00	
DRAWING NUMBER: 13	
SHEET FORMAT: A3	SCALE: 1:1
  	

A.14 Silicon Poly Pad



1. **SILICONE RUBBER, 60 SHORE A ± 5 , COLOR: BLACK**
2. **ADHESIVE: 3M 9448A DOUBLE-COATED TISSUE TAPE (OR EQUIVALENT).**
3. **MAX FLASH 0.15MM; TOLERANCES PER ISO 3302-1, CLASS M2.**
4. **SPI-B2 (MEDIUM POLISH) ON CONTACT FACE.**

THESIS TITLE:

Design, Validation and Production of an Edge Device Chassis for Machine Tools

ADVISOR & CO - ADVISOR: Massimiliano Pietro Giovanni ANNONI & Francesco BARNA**STUDENTS NAME:** Abdul MOIZ & Rifaa JAVED**MATR:** 245401 & 243988**DATE:** 26-03-2026**GRADUATION SESSION:** 2026**DESCRIPTION:** SILICON POLY PAD**DRAWING NAME:** 100.01.01.01**DRAWING NUMBER:** 14**SHEET FORMAT:** A4**SCALE:** 2:1**POLITECNICO
MILANO 1863**

Appendix B

Bill of Materials

POS.	MAIN ASSEMBLE	ASSEMBLY LEVEL 00	ASSEMBLY LEVEL 01	ASSEMBLY LEVEL 02	DESCRIZIONE	Q.tà	M/B	MATERIAL	MANUFACTURING PROCESS	WEIGHT (KGs)	COD.COMMERCIO
	100.00.00.00				EDGE DEVICE	1	-				
1		100.00.00.01			TERAVERSE CHASSIS TOP	1	M	7075	CNC Milling Operations	1.147	
2		COM-100.00.00.03			DIN RAIL MOUNTING BRACKET	2	B				DINM12CB-RC
3		COM-100.00.00.02			DIN RAIL SAMPLE	1	B				141604
4		MEC040.101021A20306 [M3X6 TCCE 8.8]			Vite Testa Cilindrica Con Esagono ISO4762-M3x10	6	B				
5		CBST56-30			M6-30 HEX HEAD SCREW	4	B				
6		SCHNORR-D.3			SCHNORR-D.3 INOX	6	B				
7		SCHNORR-D.6			SCHNORR-D.6 INOX	4	B				
		100.01.00.00			BOTTOM SUB-FRAME COMPONENT'S ASSEM	1	-				
8			COM-100.01.00.05		Mini ITX MoBo	1	B				ROG STRIX B650E-I
9			COM-100.01.00.02		CONNECTOR PIN HOUSING	1	B				1333N55_JEC
10			MEC040.101031A20316 [M3X16 TSCEI 8.8]		COUNTERSUNK SCREW M3X16	2	B				
11			COM-100.01.00.03		FLUSH MOUNT SWITCH	1	B				6023T17
12			100.01.00.01		BOTTOM SUB-FRAME BLOCK	1	M	7075	CNC Milling Operations	4.745	
13			COM-100.01.00.09		Lexar® NM790 M.2 2280 PCIe GEN 4x4 NVMe SSD	1	B				F5-5200J363D32GX2-FX5
14			COM-100.01.00.08		Flare X5 RAM DDR5-5200 CL36-36-36-83 1.25V 64GB (2x32GB)	2	B				F5-5200J363D32GX2-FX5
15			socket button head screw_iso		BUTTON HEAD M3X6 SCREW	8	B				
16			COM-100.01.00.04		CPU COOLING SINK FAN	1	B				NH-L9X65
17			COM-100.01.00.07		NVIDIA RTX™ A1000 8GB GDDR6	1	B				900-5G172-2580-000
18			COM-100.01.00.06		HDPLEX 250W GaN Passive AIO ATX Power Supply	1	B				HDPLEX 250W GaN
			COM-100.01.00.10		AMD Ryzen™ 9 7900 processor 3.7 GHz 64 MB L3	1	B				100-000000590
			100.01.01.00		SILICON POLY PAD STACK ASSEM	1	-				
19				100.01.01.01	SILICON POLY PAD	4	M	Silicon Rubber	Room Temperature Vulcanization (RTV)	0.002	

Appendix C

Component Datasheets

C.1 Mini-ITX Addendum / Design Guide

Mini-ITX Addendum Version 1.1 To the microATX Motherboard Interface Specification Version 1.2

April 2009

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Revision History

Revision Number	Description	Revision Date
1.1	Minor sentence structure corrections made. Title changed to: 'Mini-ITX Addendum Version 1.1 To the microATX Motherboard Interface Specification Version 1.2' to reflect full name of mATX document name.	Feb, 2009
1.0	Initial release.	Feb, 2009

1 Executive Summary

The Mini-ITX addendum to the *microATX Motherboard Interface Specification* details the use of the Mini-ITX form factor standard, developed by Via Technologies Inc, for compatibility with Intel based platforms. This document defines only the specific features in Intel's Mini-ITX based platforms that differ from those of microATX and should be used in conjunction with the governing microATX specification.

A smaller motherboard layout offers system developers the ability to create new and innovative system designs. This smaller version of microATX allows and encourages developers to build within the sub 8 Liter chassis volume for a variety of new applications.

Described within this document are requirements and characteristics of a Mini-ITX motherboard, so that a motherboard may function and fit appropriately when paired with a **Mini-ITX** chassis. Beyond this, it does not detail processor, memory, graphics or other system features required to meet the Mini-ITX form factor. These items are left to system designers and integrators within the guidelines of the microATX specification.

Table 1. Mini-ITX Addendum Feature Summary

Feature	Benefit
170mm x 170mm motherboard size	Smaller board size enables a smaller system size
Standard microATX 1.2 or later I/O panel	I/O shield does not need to be retooled. Motherboard can be used in a ATX or in a microATX chassis
Same motherboard mounting holes as in microATX	Compatible with microATX chassis. No need to retool current chassis
Current processor and future processor technologies	Chassis will work for multi generation socketed processor technology

This addendum does NOT define:

- Specific power supply form factors
- Thermal design guidance to chassis vendors (covered in TASC guide listed in Reference Documents)

The Mini-ITX addendum to the microATX Specification is a public document intended for widespread application in many types of systems. It is available through a public website located at:

<http://www.formfactors.org>

1.1 Terminology

Term	Description
SFF (Small form factor)	8-19 liter chassis (IDC* definition)
Ultra SFF (uSFF)	4-8 liter chassis (IDC* definition)
Tiny PC	Less than 4 liter chassis (IDC* definition)

1.2 Reference Documents

The following reference documents are posted on the public web site at <http://www.formfactors.org>

Document
microATX Motherboard Interface Specification Version 1.2
SFX 12V Power Supply Design Guide
TFX 12V Power Supply Design Guide
Thermally Advantaged Small Chassis OR TASC [pronounced 'task'] (Thermal Design Guide)

1.3 Benefits to Users

Trends in the industry indicate that users require a smaller and lower cost solution for their PC needs. The smaller board size and lower height keep out zones enable a reduced sized chassis as it sits on the user's desk, is mounted on a display, or comes in any other innovative form factor. These changes also enable a PC to be designed into various aesthetic shapes and sizes.

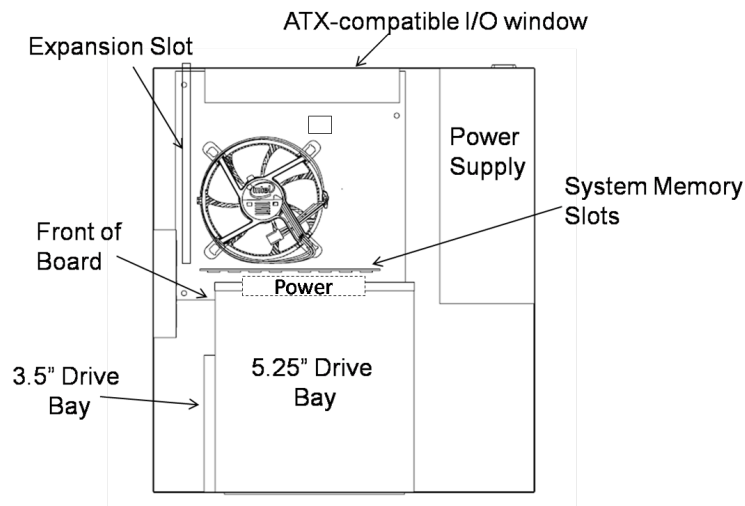
1.4 Benefits to Manufacturers

By manufacturing to this Mini-ITX specification, motherboard manufacturers and chassis manufacturers can guarantee a better compatibility between their products. They can also capitalize on the benefits of a reduction in total system costs because of a reduced system size. This specification allows chassis vendors to design their product targeting the soldered down, low power processors all the way up to high performance, multi-core processors. It eliminates the need for them to design targeted chassis for each platform.

2 *Layout*

This section describes the mechanical specification of the Mini-ITX form-factor motherboard. Size, mounting hole placement, connector placement, and component height constraints are specified. System components such as hard drives, disk drives, and power supplies are not specified, however it is generally recommended to consider what would facilitate assembly, as well as not place components such that they block fan inlets. An example layout is depicted in Figure 1.

Figure 1. Example Mini-ITX Layout



Note: Depicted system is approximately 8L with standard desktop components.

2.1 Board dimensions

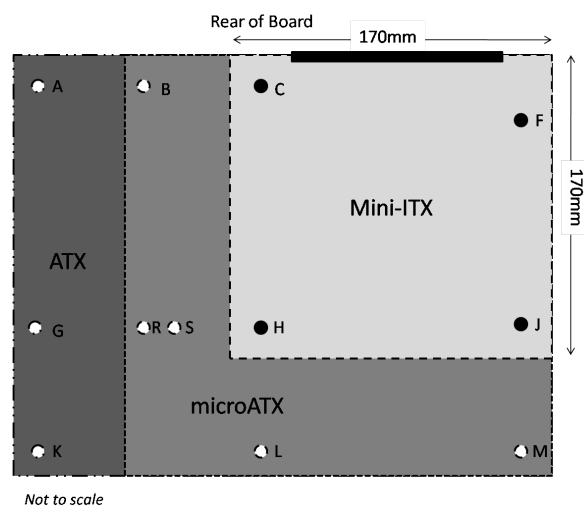
Table 2. Compares ATX, microATX, and Mini-ITX board dimensions

Dimension	ATX	microATX	Mini-ITX
Maximum width Allowable	305mm	244mm	170mm
Maximum depth Allowable	244mm	244mm	170mm

2.2 Mounting Hole Placement

Mini-ITX utilizes a subset of ATX mounting holes. To avoid damage to traces on motherboards, chassis standoffs in any locations not specified should be removable or not implemented at all. See Figure 2 for relative hole location compared to ATX and microATX motherboards.

Figure 2. ATX, microATX, and Mini-ITX Mounting Holes



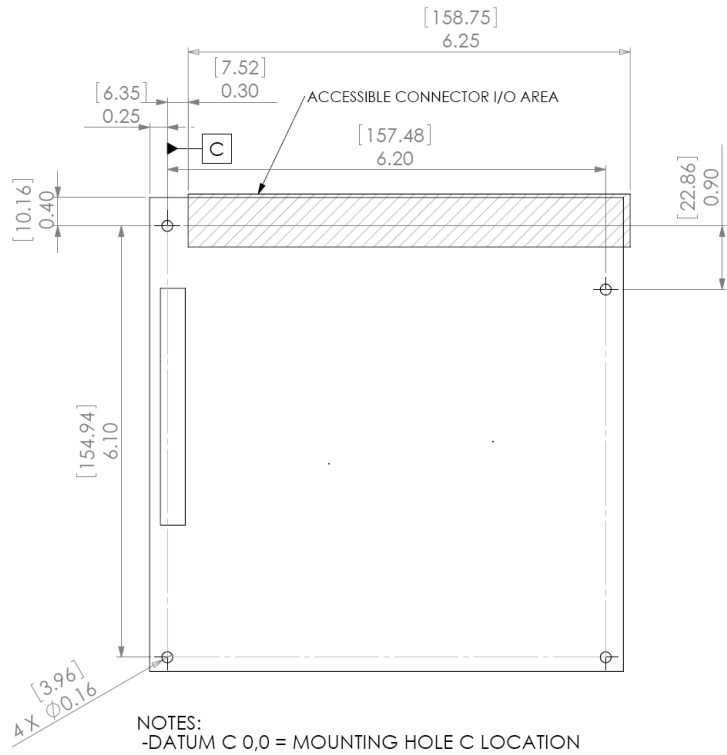
NOTE: Board is shown oriented with the rear of the board towards the top.

NOTE: The lighter portion indicates the approximate region of the Mini-ITX form factor.

Table 3. Motherboard Mounting Hole Locations

Form Factor	Mounting Hole Locations
Mini-ITX	C,F,H,J
microATX	B,C,F,H,J,L,M,R,S
ATX	A,C,F,G,H,J,K,L,M

Figure 3. Mini-ITX Board Diagram



2.3 Connector placement

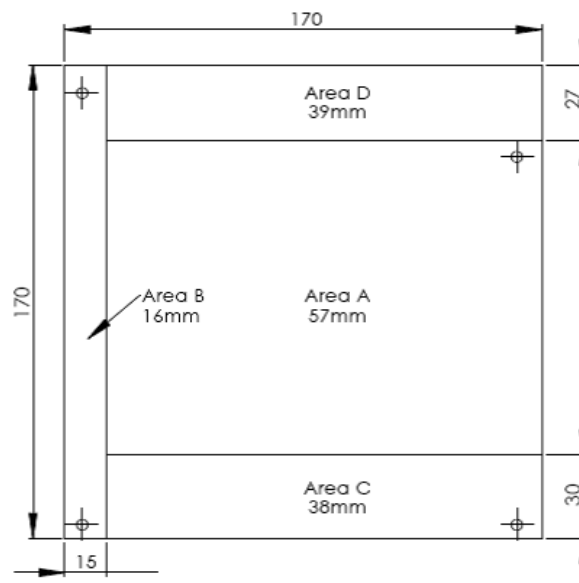
All connector locations as well as allowable placement area for I/O connectors on the back panel are described and can be found in the microATX interface specification.

2.4 Height Constraints

2.4.1 Primary (Component) Side Height Constraints

One major advantage of the Mini-ITX form factor is its backward-compatibility with the ATX specification. The Mini-ITX motherboard can be installed in any ATX chassis. Figure 4 shows the required **maximum component height constraints** for the components on the PC board. For full compliance with Mini-ITX, and to prevent interference with the chassis structure, power supply, or peripherals, the motherboard components should not exceed the height limit in each zone defined. Similarly, compliant power supplies, peripherals, and chassis features should not extend into the motherboard component area.

Figure 4. Mini-ITX Maximum Component Height Restrictions



Notes:

- All dimensions in the above figure are in millimeters (mm).
- The 57mm height restriction in Area A applies to the PC board component height. The actual height of the chassis should include any dynamic excursion considerations for shipping as well as needs to facilitate alternative cooling solutions or airflow considerations.
- For Intel boxed processor fan heat sink, it is strongly recommended not to place components between fan inlet and chassis side vent by leaving space between chassis wall and area A open.
- The component height requirement assumes a motherboard thickness of 1.57 mm (0.062").

2.4.2 Secondary (Bottom/Solder) Side Height Constraints

No height restraints on secondary side are added or removed from what is specified in the microATX Motherboard Interface Specification.

3 ***Power Supply Information***

Provided the very different needs of the platforms that fit in the small desktop form category, this specification does not attempt to define a standard for the power supply to match with the Mini-ITX motherboard specification. Instead it recommends that manufacturers consider using a:

- SFX, TFX or FlexATX are available power supply form factor for chassis greater than 5 liters
- External power adapter for chassis less than 5 liters

Refer to the microATX Motherboard interface Specification for information on power supply requirements.

C.2 AMD Ryzen 9 7900 Processor Datasheet

L2 Cache	12 MB
L3 Cache	64 MB
Default TDP	65W
Processor Technology for CPU Cores	TSMC 5nm FinFET
Processor Technology for I/O Die	TSMC 6nm FinFET
CPU Compute Die (CCD) Size	71mm ²
I/O Die (IOD) Size	122mm ²
Package Die Count	3
Unlocked for Overclocking ⓘ	Yes
AMD EXPO™ Memory Overclocking Technology	Yes
Precision Boost Overdrive	Yes
Curve Optimizer Voltage Offsets	Yes
AMD Ryzen™ Master Support	Yes
CPU Socket	AM5
Supporting Chipsets	A620 , X670E , X670 , B650E , B650 , X870E , X870 , B840 , B850
CPU Boost Technology	Precision Boost 2
Instruction Set	x86-64
Supported Extensions	AES , AMD-V , AVX , AVX2 , AVX512 , FMA3 , MMX-plus , SHA , SSE , SSE2 , SSE3 , SSE4.1 , SSE4.2 , SSE4A , SSSE3 , x86-64
Thermal Solution (PIB)	AMD Wraith Prism
Max. Operating Temperature (Tjmax)	95°C
Launch Date	01/14/2023
*OS Support	Windows 11 - 64-Bit Edition , Windows 10 - 64-Bit Edition , RHEL x86 64-Bit , Ubuntu x86 64-Bit

Connectivity

Native USB 3.2 Gen 2 (10Gbps)	4
Native USB 3.2 Gen 1 (5Gbps)	0
Native USB 2.0 (480Mbps)	1
Native SATA Ports	0
PCI Express® Version	PCIe® 5.0
Native PCIe® Lanes (Total/Usable)	28 , 24
Additional Usable PCIe Lanes from Motherboard	X670E 12x Gen4
	X670 12x Gen4
	B650E 8x Gen4
	B650 8x Gen4
NVMe Support	Boot , RAID0 , RAID1 , RAID10
System Memory Type	DDR5
Memory Channels	2
Max. Memory	128 GB
System Memory Subtype	UDIMM
Max Memory Speed	2x1R DDR5-5200
	2x2R DDR5-5200
	4x1R DDR5-3600
	4x2R DDR5-3600
ECC Support	Yes (Requires mobo support)

Graphics Capabilities

Graphics Model	AMD Radeon™ Graphics
Graphics Core Count	2
Graphics Frequency	2200 MHz
USB Type-C® DisplayPort™ Alternate Mode	Yes

C.3 Noctua NH-L9x65 chromax.black Datasheet



NOCTUA NH-L9x65 chromax.black

L-Type Premium Cooler

The NH-L9x65 chromax.black is an all-black version of the award-winning NH-L9x65 low-profile cooler, which covers a middle ground between the larger NH-L12 series and the ultra-compact NH-L9i and NH-L9a series. With 65 instead of 37mm height and four instead of two heatpipes, the NH-L9x65 is more powerful than its smaller siblings yet retains the NH-L9i's 95x95mm footprint, which not only guarantees 100% RAM and PCIe compatibility on current motherboards but also makes the cooler more convenient to work with as it doesn't overhang near-socket connectors. Thanks to the highly optimised NF-A9x14 premium fan that supports fully automatic speed control via PWM, the NH-L9x65 runs remarkably quiet. Topped off with the professional SecuFirm2™ multi-socket mounting system for Intel and AMD, Noctua's renowned NT-H1 thermal compound and a 6 year manufacturer's warranty, the NH-L9x65 fuses everything users have come to expect from Noctua's larger coolers into a compact premium package for space restricted systems.

Award-winning NH-L9x65 cooler

Carrying awards and recommendations from more than 100 hardware websites and magazines across the world, the NH-L9x65 has proven its qualities in countless tests. Its winning combination of low height, strong performance and excellent compatibility has made it a default choice for Small Form Factor builds.

chromax.black design

The NH-L9x65 chromax.black is black from head to toe: featuring a black coated heatsink, a black fan with black anti-vibration pads, black fan clips and black mounting parts, it's right at home in all-black builds and easy to integrate with other colour schemes.

100% RAM compatibility

With its compact 95x95mm footprint, the NH-L9x65 does not overhang the RAM slots on Intel LGA1851/LGA1700/LGA1200/LGA115x and AMD AM5/AM4 based motherboards, which ensures easy access to the modules and 100% compatibility with DIMMs that feature tall heat-spreaders or RGB lighting.

6-year manufacturer's warranty

Noctua products are renowned for their impeccable quality and outstanding longevity. Like all Noctua fans, the supplied NF-A9x14 features an MTTF rating of more than 150.000 hours and the entire NH-L9x65 package comes with a full 6-year manufacturer's warranty.

NH-L9x65 HEATSINK SPECIFICATIONS

Socket compatibility	Intel LGA1851, LGA1700, LGA1200, LGA1156, LGA1155, LGA1151, LGA1150 and AMD AM5, AM4
Dimensions	95x95x51 mm
Dimensions with NF-A9x14 HS-PWM	95x95x65 mm
Weight	340 g
Weight with NF-A9x14 HS-PWM	413 g
Material	Copper (base and heat-pipes), aluminium (cooling fins), soldered joints & nickel plating
Fan compatibility	92x92x14 mm, 92x92x25 mm

NF-A9x14 HS-PWM FAN SPECIFICATIONS

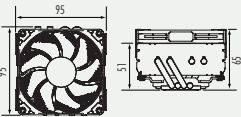
Size	92x92x14 mm	
Connector	4-pin PWM	
Bearing	SS02	
Blade geometry	A-Series with Flow Acceleration Channels	
Frame technology	AAO (Advanced Acoustic Optimisation)	
Max. input power	2.52 W	
Voltage	12 V	
MTTF	> 150,000 h	
NF-A9x14 HS-PWM	without adaptor	with L.N.A.
Max. rotational speed (+/-10%)	2500 RPM	1800 RPM
Max. airflow	57.5 m³/h	40.8m³/h
Max. acoustical noise	23.6 dB(A)	14.8 dB(A)
Max. static pressure	2.11 mmH ₂ O	1.06 mmH ₂ O

LOGISTIC DATA

Product name	Noctua NH-L9x65 chromax.black
EAN	9010018000498
UPC	841501100499
Packaging dimensions (HxWxD)	180x134x133 mm
Weight incl. packaging	880 g
Warranty	6 years
Packaging unit	12 pcs
Packaging dimensions / unit (HxWxD)	438x384x306 mm
Weight incl. packaging / unit	11.60 kg

SCOPE OF DELIVERY

- Black NH-L9x65 heatsink
- NF-A9x14 HS-PWM chromax.black premium fan
- Low-Noise Adaptor (L.N.A.)
- NT-H1 thermal compound
- Black SecuFirm2™ mounting-kit
- Noctua metal case-badge



CHROMAX
by NOCTUA

www.noctua.at

C.4 NVIDIA RTX A1000 Datasheet

Datasheet



NVIDIA RTX A1000

Mighty performance. Minimal footprint.



Small Size, Big Impact—The Ultimate Compact Power

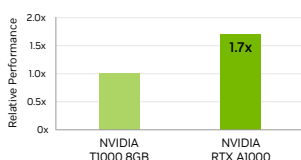
The NVIDIA RTX™ A1000 is a powerful, low-profile GPU that brings RTX-powered real time ray tracing and AI acceleration to a whole new audience. Built on the NVIDIA Ampere GPU architecture, it combines 2,304 CUDA® Cores, 72 third-generation Tensor Cores, and 18 second-generation RT Cores, and 8GB of GDDR6 graphics memory. With the RTX A1000, you can create more compelling visuals, explore new AI-powered workflows, and boost your productivity, all from a small-form-factor solution.

NVIDIA RTX professional graphics cards are certified for a broad range of professional applications, tested by leading independent software vendors (ISVs) and workstation manufacturers, and backed by a global team of support specialists. Get the peace of mind to focus on what matters with the premier visual computing solution for mission-critical business.

Key Features

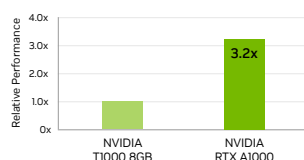
- > Second-generation RT Cores
- > Third-generation Tensor Cores
- > PCI Express Gen 4
- > Four Mini DisplayPort 1.4a
- > AV1 decode support
- > DisplayPort with audio
- > NVIDIA RTX Experience™
- > NVIDIA RTX Desktop Manager software
- > NVIDIA RTX IO support
- > HDCP 2.2 support
- > NVIDIA Mosaic¹ technology

Graphics



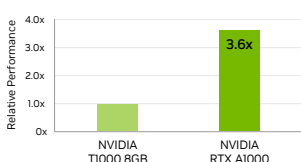
Tests run on an Intel Core i9-12900K Processor @ 3.2GHz (5.2GHz Turbo), 64GB RAM, Windows 11 Enterprise x64, SPECviewperf 2020, NVIDIA Driver 551.57. Relative speedup for 4K Maya score. Performance based on pre-release build, subject to change.

Rendering



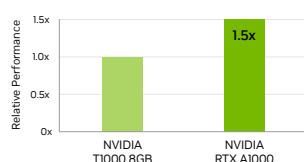
Tests run on an Intel Core i9-12900K Processor @ 3.2GHz (5.2GHz Turbo), 64GB RAM, Windows 11 Enterprise x64, NVIDIA Driver 551.57. Relative speedup for 1080p resolution Arnold render tests. Performance based on pre-release build, subject to change.

Generative AI



Tests run on an Intel Core i9-12900K Processor @ 3.2GHz (5.2GHz Turbo), 64GB RAM, Windows 11 Enterprise x64, Stable Diffusion WebUI v1.7.0 with TensorRT extension, NVIDIA Driver 551.57. Average relative speedup for 512x512 image generation. Performance based on pre-release build, subject to change.

CAD



Tests run on an Intel i9-12900K @ 3.2GHz, 5.20GHz Turbo, 64GB RAM, Windows 11 Enterprise x64, NVIDIA driver 551.57. Results based on SOLIDWORKS 2022 FSAA On, GPU composite scores. Preliminary results on pre-production hardware and software, final performance may vary.

Specifications	
PNY Part Number	VCNRTXA1000-PB
EAN code	3536403399467
GPU memory	8GB GDDR6
Memory interface	128-bit
Memory bandwidth	192GB/s
NVIDIA Ampere-based CUDA® Cores	2304
NVIDIA third-generation Tensor Cores	72
NVIDIA second-generation RT Cores	18
Single-precision performance	6.7 TFLOPS²
RT Core performance	13.2 TFLOPS²
FP16 Tensor performance	53.8 TFLOPS³
Peak INT8 Tensor performance	107.8 TOPS⁴
System interface	PCIe 4.0 x8⁵
Power consumption	Total board power: 50W
Thermal solution	Active
Form factor	6,9 cm H x 16,3 cm L, single slot
Display connectors	4x Mini DisplayPort 1.4a
Max simultaneous displays	4x 4096 x 2160 @ 120Hz 4x 5120 x 2880 @ 60Hz 2x 7680 x 4320 @ 30Hz
Encode/decode engines	1x encode, 2x decode (+AV1 decode)
Graphics APIs	DirectX 12, Shader Model 6.6, OpenGL 4.6⁶, Vulkan 1.3⁶

Ready to get started?

To learn more about the NVIDIA RTX A1000, visit:
[nvidia.com/rtx-A1000](https://www.nvidia.com/rtx-A1000)

1 Windows 10 and Linux. | 2 Peak rates based on GPU Boost Clock. | 3 Effective FP16 teraFLOPS (TFLOPS) using the sparsity feature. | 4 Peak INT8 TOPS with sparsity. | 5 RTX A1000 utilizes a full-length PCIe Gen 4 x8 interface. | 6 Product is based on a published Khronos specification and is expected to pass the Khronos conformance testing process when available. Current conformance status can be found at www.khronos.org/conformance

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C.5 HDPLEX 250W GaN AIO ATX PSU Datasheet

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[Accessories](#)▾ [Customer Reviews](#)

[HDPLEX 250W GaN Passive AIO ATX](#) [Overviews](#) [Buy Now](#) [Specs](#) [Package Content](#)

Power Supply

Technical Specifications

Wattage: 250W (94% Efficiency).

Input Voltage: 90V-264V 50/60hz

Idle Power: <0.4W/0.1W

Feature

- GaN All-In-One ATX Power Supply
- Smallest ATX PSU in the World!
- Fully Passive and Fanless, Zero db Operation
- PFC+LLC Structure, Level 5 Energy Efficiency
- Two Auto Grade GaN FETs on PFC Stage and Two on LLC Stage
- 1.18W/cm³ Super High Power Density
- Support Sync with a Second Unit
- Aluminum shell casing working with HDPLEX fanless PC chassis to dissipate heat
- Fanless and 100% Silent
- 4 Layer 2oz Copper PCB for high current and fast heat dissipation
- Three Stage AC Input Filter Eliminate Grid Noise
- Unibody Flat transformer eliminates noise caused by vibration.
- High Precision 1% Resistor

- Four ATX 1KV 8A TTR8MF Full-wave Rectification
- 150μF Rubycon filter CAP and 9000μF Solid Cap
- UVP, OVP, SCP, OPP, OTP
- Fully Modular ATX Output
- Detachable C14 IEC Connector:flexible to support other AC input for custom project

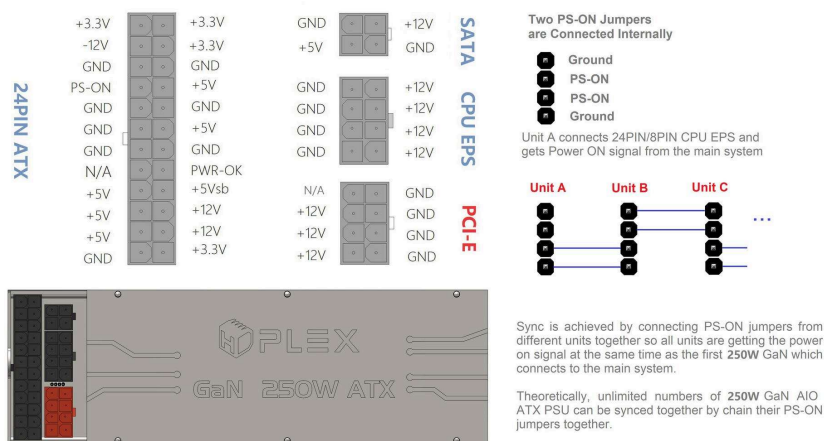
Size: 170(D) x 55 (W) x 25 (H) mm, **Weight:** 360 gram/13 oz,

[HDPLEX 250W GaN AIO ATX PSU 3D Engineer Drawing \(STP\) Download Here](#)

Operating Temperature: -10°C - 75°C

AC Input	100-240VAC 50/60Hz				
DC Output	+3.3V	+5V	+12V	-12V	+5Vsb
MAX Output Current	10A	10A	20A	1A	5A
MAX Combined Power	80W				
Total Power	250W				

HDPLEX 250W GaN AIO ATX PSU Diagram



Molex Part Number for HDPLEX 250W GaN

C.6 G.Skill Flare X5 DDR5 Memory Datasheet



F5-5200J3636D32GX2-FX5

Flare X5
DDR5-5200 CL36-36-36-83 1.25V
64GB (2x32GB)
Intel XMP / AMD EXPO

Designed for DDR5-enabled AMD AM5 platforms, Flare X5 series DDR5 memory is built for high performance in a low-profile design. Featuring AMD EXPO overclocking profiles for easy memory overclocking, users can easily enable overclocked performance by simply enabling EXPO in the BIOS on compatible systems.

Check memory compatibility for your motherboard with the [RAM Configurator](#) tool, or check the [QVL](#) for a list of compatible motherboards with this memory kit.

Overview

Memory Type	DDR5
Capacity	64GB (32GBx2)
Multi-Channel Kit	Dual Channel Kit
OC Profile Support	Intel XMP 3.0 / AMD EXPO
Tested Speed (Up To) (XMP/EXPO)	5200 MT/s
Tested Latency (XMP/EXPO)	36-36-36-83
Tested Voltage (XMP/EXPO)	1.25V
Registered/Unbuffered	Unbuffered
Error Checking (ECC)	Non-ECC
SPD Speed (Default)	4800 MT/s
SPD Voltage (Default)	1.10V



Warranty	Limited Lifetime
Features	Intel XMP 3.0 & AMD EXPO Profile Ready
Additional Notes	- Do not mix memory kits. Memory kits are sold in matched kits that are designed to run together as a set. Mixing memory kits will result in stability issues or system failure. - Memory kits that are "Intel XMP 3.0 Ready" / "AMD EXPO Profile Ready" includes support for the respective OC profile. - Prior to enabling XMP or EXPO, memory kits will boot at the SPD speed at default BIOS settings with compatible hardware. - For memory kits with XMP or EXPO, enable XMP/EXPO/DOCP/A-XMP profile in BIOS to reach up to the rated potential XMP or EXPO overclock speed of the memory kit, subject to the use of compatible hardware. Enabling XMP or EXPO is an act of overclocking and requires BIOS setting adjustments. Please refer to the "How to Enable XMP/EXPO" guide. - Reaching the rated XMP/EXPO overclock speed and system stability will depend on the compatibility and capability of the motherboard and CPU used. - Usage in any manner inconsistent with manufacturer specifications, warnings, designs, or recommendations will result in lower speeds, system instability, or damage to the system or its components. - Memory module height can be found in the FAQ, under the question "How tall are the memory modules?". - For product support and related questions, please contact the G.SKILL technical support team via email.

1. All images and descriptions are for illustrative purposes only. Please refer to the specifications page for product details.
2. All product specifications and appearances are subject to change without notice. Please check with your retailer or supplier for exact offers. Products may not be available in all markets.
3. Exact specifications and features vary by model. Please refer to the specifications page for product details.
4. PCB color is subject to change without notice.
5. Third-party software support and compatibility depends on software version and operating environment, and are subject to change without notice.
6. Although we strive to present precise and comprehensive information at the time of publication, a small number of items may contain typographic or photographic errors.
7. The product (electrical or electronic equipment) should not be placed in municipal waste. Check local regulations for proper disposal of electronic products.
8. The use of trademark symbols (TM, ®) appearing on this website means that the word text, trademarks, logos, or slogans, is being used as trademark under common laws protection and/or registered as Trademark in U.S. and/or other country/region.
9. Brand names, product names, and trademarks mentioned are properties of their respective companies or owners.
10. Unless otherwise stated, all performance claims are based on theoretical performance. Actual figures may vary in real-world situations.



C.7 Lexar NM790 PCIe Gen4 SSD Datasheet

HOT





Lexar® NM790 M.2 2280 PCIe Gen 4

Sequential read up to 7400MB/s, sequential write up to 6500MB/s

8TB

4TB

2TB

1TB

◦ Compare

◦ Compatibility

 Share

 Share



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Lexar® NM790 M.2 2280 PCIe Gen 4x4 NVMe SSD



High-speed Performance



PCIe Gen4x4 Interface

Overview

Specs

Support



3D TLC NAND

Specifications

Capacities	512GB/1TB/2TB/4TB/8TB
Form Factor	M.2 2280
Interface	PCIe Gen4x4
Speed	512GB: Read speed up to 7200MB/s ¹ , write speed up to 4400MB/s ¹ , random read and write speeds of up to 800,000 IOPs

	1TB: Read speed up to 7400MB/s ¹ , write speed up to 6500MB/s ¹ , random read up to 1,000,000 IOPs, random write up to 900,000 IOPs 2TB: Read speed up to 7400MB/s ¹ , write speed up to 6500MB/s ¹ , random read up to 1,000,000 IOPs, random write up to 900,000 IOPs 4TB: Read speed up to 7400MB/s ¹ , write speed up to 6500MB/s ¹ , random read and write speeds of up to 900,000 IOPs 8TB: Read speed up to 7000MB/s ¹ , write speed up to 6200MB/s ¹ , random read up to 850,000 IOPs, random write up to 900,000 IOPs
Operating Temperature	0°C to 70°C (32°F to 158°F)
Storage Temperature	-40°C to 85°C (-40°F to 185°F)
Dimensions (L x W x H)	512GB-4TB: 80 x 22 x 2.45 mm (3.15" x 0.87" x 0.10") 8TB: 80 x 22 x 3.75 mm (3.15" x 0.87" x 0.148")
Weight	512GB-4TB: 6g / 0.013 lbs 8TB: 7.6g / 0.017 lbs
Warranty	Five-year limited warranty
Shock-resistant	1500G, duration 0.5ms, Half Sine Wave
Vibration-resistant	10~2000Hz, 1.5mm, 20G, 1 Oct/min, 30min/axis (X,Y,Z)
TBW	512GB: 500TBW, 1TB: 1000TBW, 2TB: 1500TBW,4TB: 3000TBW, 8TB: 6C TBW
MTBF	1,500,000 Hours

¹ Up to 7400MB/s read transfer, up to 6500MB/s write. Speeds based on internal testing. Actual performance may vary.

² Comparison based on internal testing. Actual performance may vary.

Product Numbers

C.8 IEC C14 Panel Mount Connector Datasheet



IEC Connector

Screw-on Male, Quick-Disconnect Terminal, C14, 10A UL



1-49 Each \$5.05

50-249 \$4.29

250 or more \$3.53

1333N55

Connection Type	Straight Blade
Electrical Connector Component	Receptacle
Receptacle Type	Single
Gender	Male
Shape	Straight
IEC Style	C14
Grounding	Grounded
Number of Blades	3
Voltage	250V AC
Current (Rating)	10A (UL), 10A (IEC)
Frequency	50 Hz, 60 Hz
Wire Connection Type	Quick-Disconnect Terminals
Terminal	
Length	0.93"
Width	1/4"
Thickness	0.032"
For Fuse	
Overall Length	20 mm
Overall Diameter	5 mm
Housing Material	Plastic
Mount Type	Screw On
Mounting Location	Panel
For Panel Cutout	
Height	1.24"
Width	1.08"
For Panel Thickness	0.24"
Mounting Hole Diameter	0.14"
Number of Mounting Holes	2
Temperature Range	-10° to 155° F
Environmental Rating	IP40
Shock Protection Class	I
Specifications Met	UL Recognized Component, C-UL Recognized Component, UL 94 V-0, CSA Certified, CE Marked, IEC 60320, ENEC Marked
Color	Black
RoHS	RoHS 3 (2015/863/EU) compliant with exemption 6(c) - Lead in copper alloy
REACH	REACH (EC 1907/2006) (06/25/2025, 250 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Czech Republic
Schedule B	853669,5050
ECCN	EAR99

Pair these connectors with standard IEC power cords to bring power into or out of your electronic devices. Often used to convey power from wall outlets, there's no need to wire your devices to an external power source. Instead, wire these connectors into your device with the terminals on the back of each connector. Most meet U.S. or international standards for safety.

Receptacles are often installed in electrical devices.

Most also include shock protection.

Class I shock protection means they're insulated and have a protective ground to prevent electrical shocks.

Male receptacles are commonly used to bring power into an electronic device. Some accept a fuse to prevent short circuits and circuit overloads from damaging your devices. The fuses are sold separately.

Screw-on connectors mount to devices with any panel thickness, as long as you can drill mounting holes into the device.

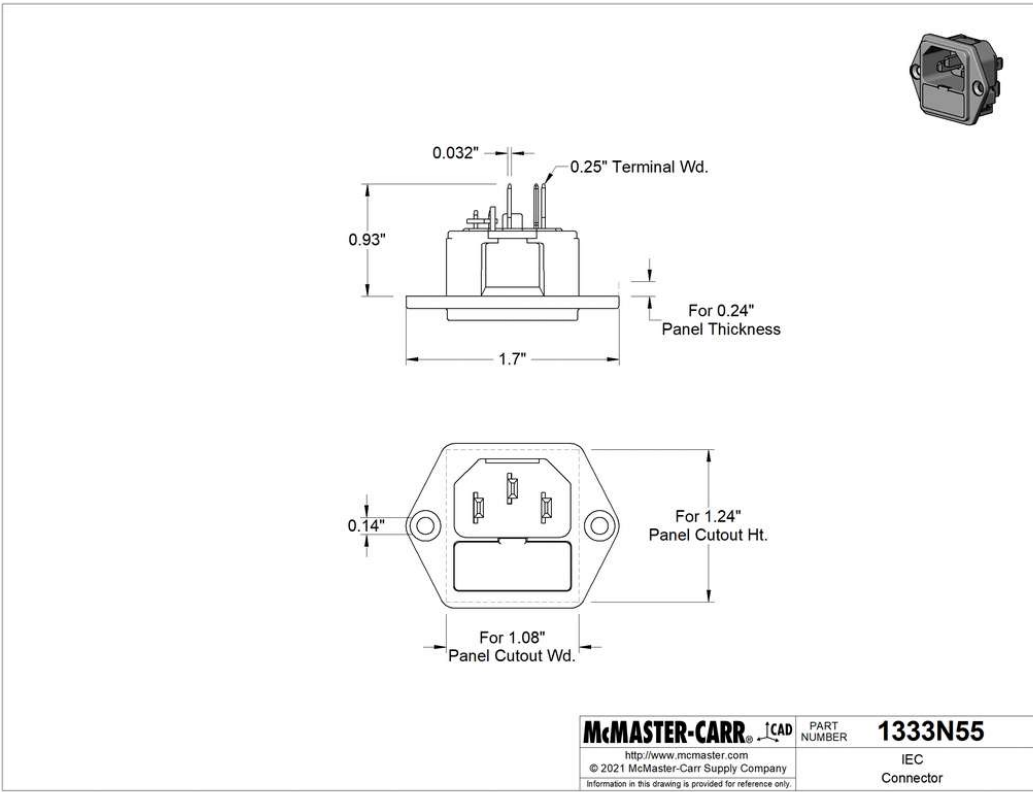
Quick-disconnect terminal wire connections are faster to wire than screw and tab terminal connections. The terminals slide together with the quick-disconnect terminals on your wiring and are easily disconnected by hand, but still provide a strong hold.

IP-rated connectors meet standards for protecting you from making contact with a live circuit. The larger the first digit, the smaller the object it protects against.

And an IP40 rating means wire and other objects larger than 1 mm won't get in.

Connectors with a UL 94 rating have passed one of UL's flame tests.

UL 94 V-0 means they self-extinguish within 10 seconds if they catch fire and won't spread flames from dripping.

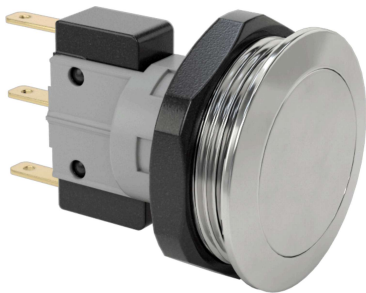


The information in this 3-D model is provided for reference only.

C.9 22mm Flush Push Button Switch Datasheet



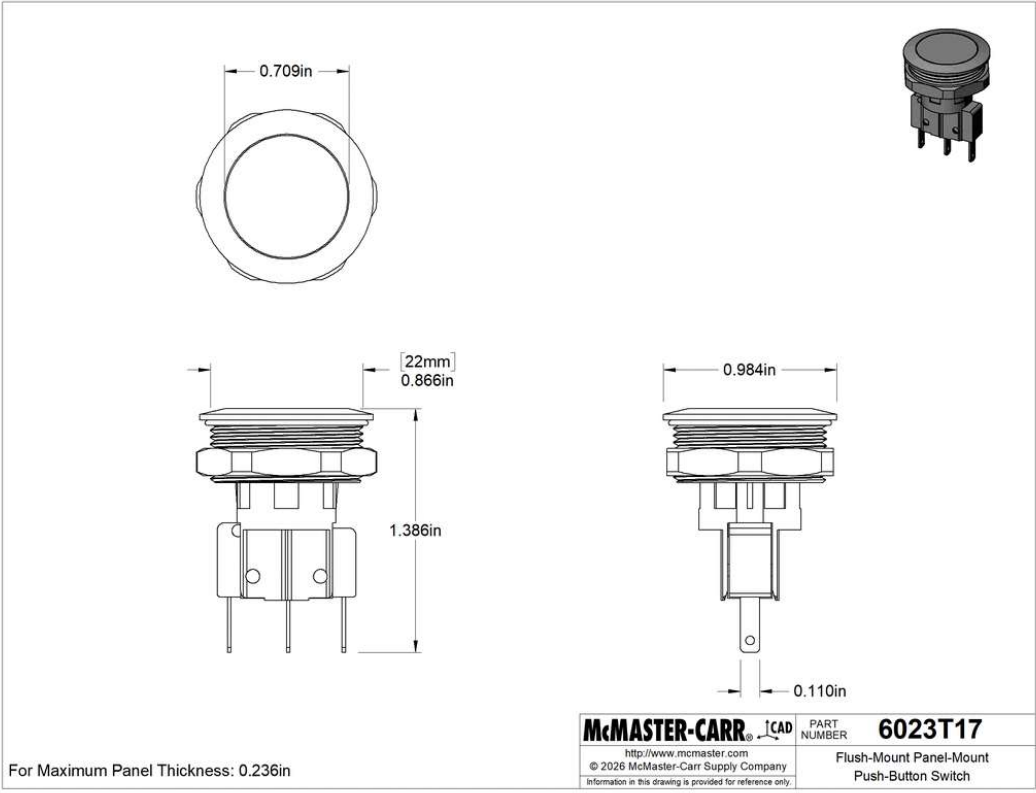
Flush-Mount Panel-Mount Push-Button Switch for 22 mm Panel Diameter



\$21.29 Each
6023T17

Switch Type	Manual
Mounting Location	Panel
For Panel Cutout Diameter	22 mm
For Panel Cutout Diameter	7/8"
Actuator Style	Push Button
Push-Button Style	Flush
Push-Button Shape	Round
Actuator Material	Stainless Steel
Actuator Base Material	Stainless Steel
Illumination	Not Illuminated
Number of Circuits Controlled	1
Switch Starting Position	1 Off (Normally Open) or 1 On (Normally Closed)
Switch Action	Springs Back (Momentary)
Number of Terminals	3
Industry Designation	SPDT
Switching Current @ Voltage	5 A @ 250 V AC/30 V DC
Maximum Voltage	30V DC 250V AC
Diameter	1"
For Maximum Panel Thickness	3/8"
Depth Behind Panel	1 5/16"
Wire Connection Type	Quick-Disconnect Terminals
Quick-Disconnect Tab Width	0.11"
Environment	Submersible
Environmental Rating	IP40, IP67, IK08
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/25/2025, 250 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Switzerland
Schedule B	853650.9035
ECCN	EAR99

Because these switches mount flush against a panel, they're easy to clean and hard to damage. They're rated IP67 for protection from temporary submersion.



The information in this 3-D model is provided for reference only.