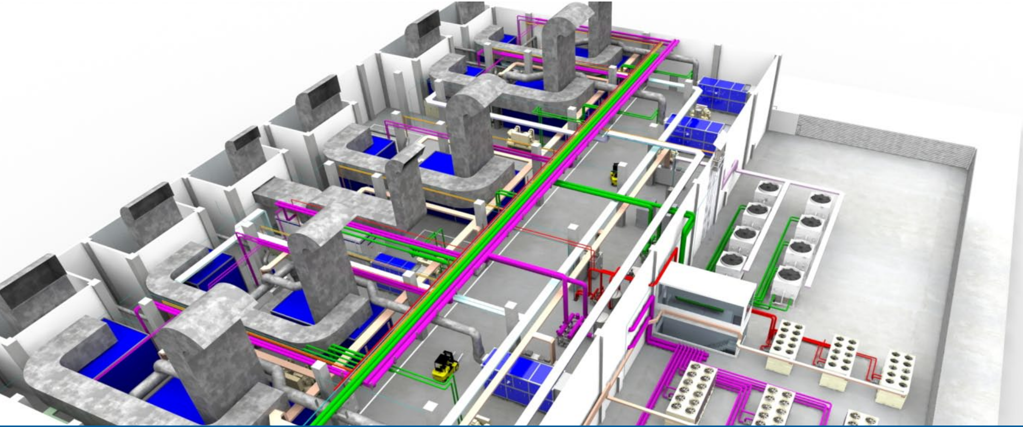

AVL FACILITY ENGINEERING, SYSTEM INTEGRATION & TURNKEY HANDBOOK

AVL Instrumentation & Test Systems

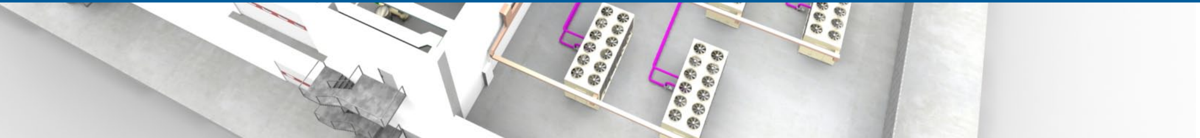

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Table of Contents

Objective

AVL is pleased to present this Workbook and hope you will find it helpful.

The purpose of this document is to provide with a comprehensive overview about the services and products AVL is able to offer for test facility design engineering (engine, powertrain, vehicle, hybrid and electrification) and together with the wide AVL portfolio from the different BU's, provide the Customer with a functional solution, starting with a clear definition of requirements and drafting of concepts, sign-off of detailed drawings for the facility construction up to turnkey delivery

As the project definition and engineering stages could vary in different parts of the world, efforts have been made so that the information presented herewith fits most of the countries where our Customer's are located.

The document provides with definitions, tools and graphical examples to support a clear definition of responsibilities with the Customer and the project stakeholders.

Please feel free to use this information for your work.
An electronic version of this workbook is available at:

Introduction

The increasing demand of reduction of Emissions, ensure fuel Economy and compliance with the emissions regulations, the future trends in regards of new mobility systems such as Electrical and offer new driving experiences to Customers, is calling for the most advanced tools to allow the automotive manufacturers perform their testing tasks in both Research and Development and Production activities.

While the instrumentation and test systems are the key to produce the results required by the Client for the different test procedures, the infrastructure where the test is performed is equally important to ensure its accuracy and repeatability.

Since design and engineering of testing facilities is getting more complex thus requires higher levels on expertise, Customer's are often relying in partners to support the engineering tasks and in some cases its construction, maintenance and even its operation.

With the in-house knowledge of Powertrain Engineering and Instrumentation and Test Systems, for the last 15 years AVL has been supporting Customers in the design of test facilities with good and proven results and with more than 50 references worldwide and therefore can proudly state the we are a reliable partner for the Customer's project's.

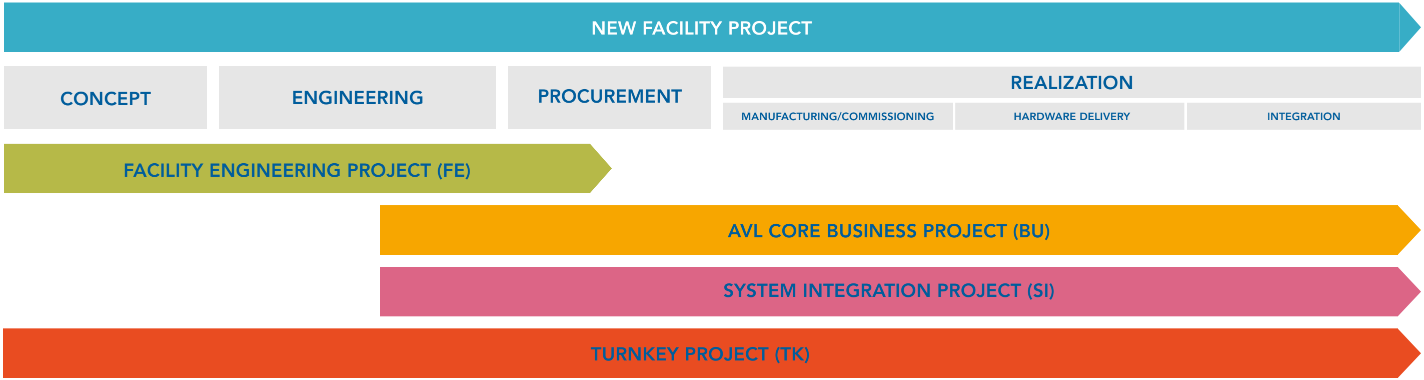
The following chapters describe the work methodology, examples and tools that you can use to configure the best model that could fit to your project.

Definitions

Facility Engineering (FE): paper delivery consisting in drawings, specification and know-how for test cells / facilities

System Integration (SI): paper and hardware delivery consisting in engineering services for specific facility systems including hardware that needs to be integrated into third party of AVL test beds

Turnkey (TK): delivery consisting of a fully functional test facility or test bed module that embraces design, construction and test equipment



Fundamentals of Building Project Plans

Every country has it own way of structuring and organizing building projects. The structure is normally defined in key stages that are usually dictated by and official entity such as the architectural or design firms and while the number of part or stages could vary in number in different countries, in mainly pursue the same main objectives identified as follows:

- Identify customer plans
- Define the project objectives and assembly the project team
- Undertake feasibility studies
- Estimate a budget plan
- Prepare comprehensive technical documents to allow tendering processes
- Finalize the design for construction
- Initiate construction
- Handover and close-down

References from the following sources have been used to support the methodology that will be explained in the following chapters so as to ensure coverage to most of AVL markets:

RIBA	UK	Royal Institute of British Architects
HOAI	Germany	Honorarordung für Architekten und Ingenieure
RD2512/1977	Spain	Real Decreto 2512/1977, del 17 de Junio. Tarifas de honorarios de los arquitectos
IAB	Brazil	Instituto de Arquitectos do Brasil
ACE-CAE	Europe	Architects Council of Europe - Conseil des Architectes d’ Europe
AGC OF AMERICA	US	The Associated General Contractors of America

AVL Facility Engineering Methodology

AVL Methodology follows 6 stages for the execution of a complex project. Methodology fits to both the traditional planning methods and BIM technology.

- Phase 1 - Concept Design
- Phase 2 - Preliminary Design
- Phase 3 - Definitive Design
- Phase 4 - Detailed Design
- Phase 5 - Procurement
- Phase 6 - Realization

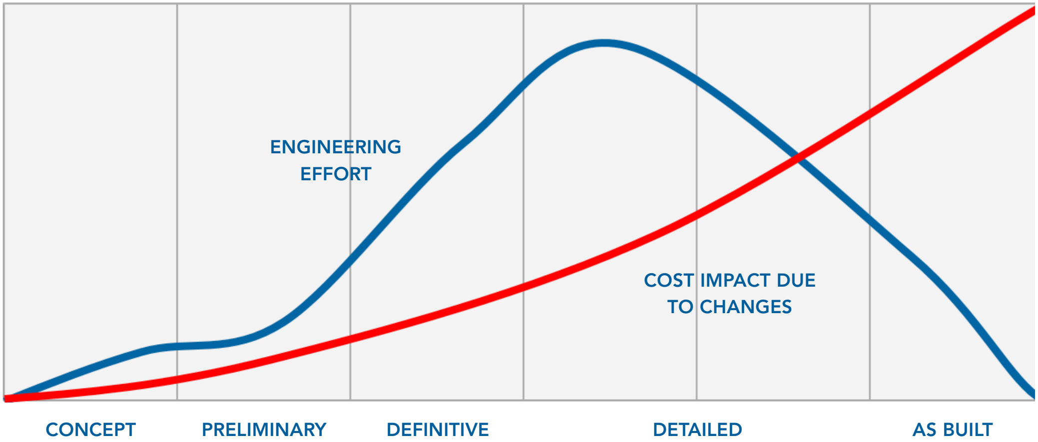
Whereas phase 1 is fundamentally associated to consulting services, phases 2, 3 and 4 are specific for design engineering, 5th for procurement and 6th to construction management.

Quality gates at each stage are defined and clear milestones are established

AVL Facility Engineering Project Phases

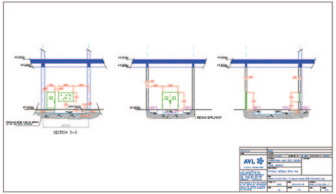
When analyzing the dedicated effort during the project life cycle, can be noticed an exponential increase in both definitive design and detailed design according to the following graph.

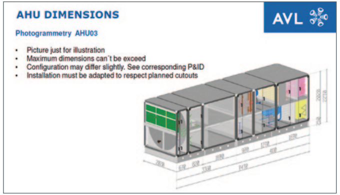
Therefore changes in specification at those stages are critical as could have a substantial impact in the overall project cost.



The AVL Solution

CONSULTANCY	ENGINEERING	PROCUREMENT	CONSTRUCTION MANAGEMENT
• Feasibility studies • Definition of test methodologies • Construction cost estimations • Environmental impact studies • Modular vs brick and mortar	• Preliminary Design • Definitive Design • Detail Design • Detailed Design review	• Specification Design • Definition of key suppliers • Definition of acceptance criteria • Evaluation of technical proposals • Acceptance tests	• Facility equipment • Modular test cells • Systems integration and Turnkey • Ramp-up support • After-sales service



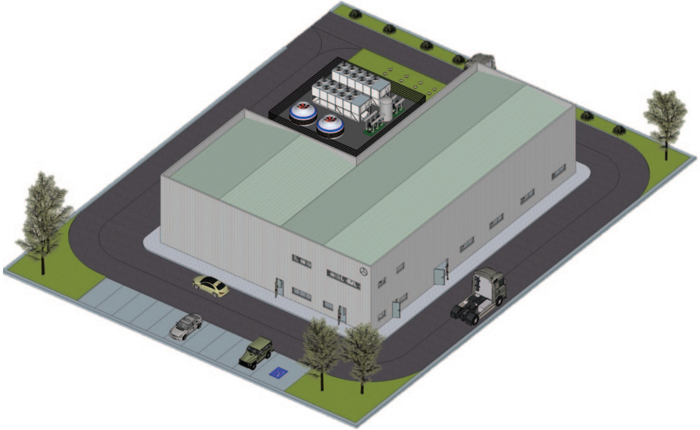


1 CONCEPT | 2 PRELIMINARY DESIGN | 3 DEFINITIVE DESIGN | 4 DETAILED DESIGN | 5 PROCUREMENT | 6 REALIZATION

Core Objectives	Key Tasks	Input requirement	Typical deliverables	Information Exchange	Equivalences
• Identify (or prepare) Clients business case by collecting key information • Undertake Feasibility Studies	• Project kick-off meeting with Customer • Project information collecting. • Workshop to define project objectives • Evaluation of existing documentation • Initial considerations to assembly the project team • Agreed idea about the project/study outcome	• Quantity and application of test facilities • Boundary conditions (available land, footprint, local site limitations, existing utility services, etc.) • Country or customer special requirements or restrictions	CONCEPT STUDY • Summary of necessities (URS) • Work process diagram • Outline drawings • Initial investment approach • Preliminary calculations • Interim table top drawing (TTD) showing proposed equipment configuration • 3D Sketch (architectural design)	• Not required	• BIM: 0 • RIBA: Phase 0,1 • US: N/A • HOAI: Phase 1

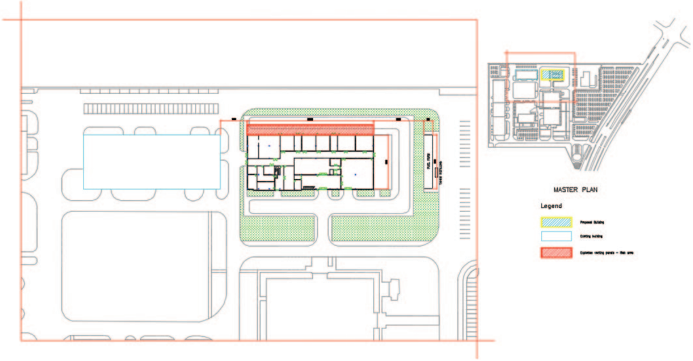
	Chilled Water (kW)	HVAC Heat Pump (kW)	Process Cooling Water (kW)	Fresh Water (kW)	Fuel (kg/h)	Compressed Air (lpm)	Exhaust (m^3/h)	Power Clean Grid (KVA)	Power Rough Grid (KVA)
Max	1.933	1.515	1.070	52	320	4.243	30.500	469	1.781
Average	1.427	1.515	642	39	192	3.182	22.500	352	1.069

Preliminary calculations

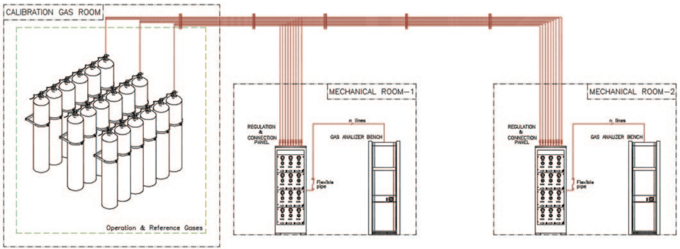


3D sketch

Core Objectives	Key Tasks	Input requirement	Typical deliverables	Information Exchange	Equivalences
• Develop Project Objectives (including scope, time, quality and cost) • Undertake Feasibility Studies • Review site information	• Workshop with the Customer • Evaluation of Customer requirements • Definition of general dimensions • Comparison and evaluation of different layout solutions • Comparison and evaluation of different constructive and architectural concepts • Definition of block diagrams for utilities and first calculations on overall utility requirements	• Feedback of Phase 1	PROJECT INCEPTION REPORT • Preliminary Project Report: Hi level summary of the project objectives defined • Update of URS - User Requirement Specifications • Preliminary Site Plan • Preliminary Building Layout • Utility requirements and definition of diversity factors • Process block diagrams for utility services • Test cells layouts • Preliminary Time Plan • Preliminary Investment Plan • Input for the environmental impact assessment studies (if required)	• Required	• BIM: 1 • RIBA: Phase 1 • US: LOD100 • HOAI: Phase 2



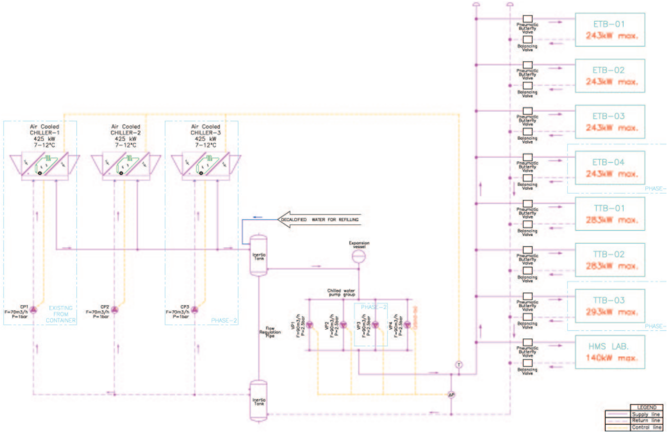
Preliminary Site Plan



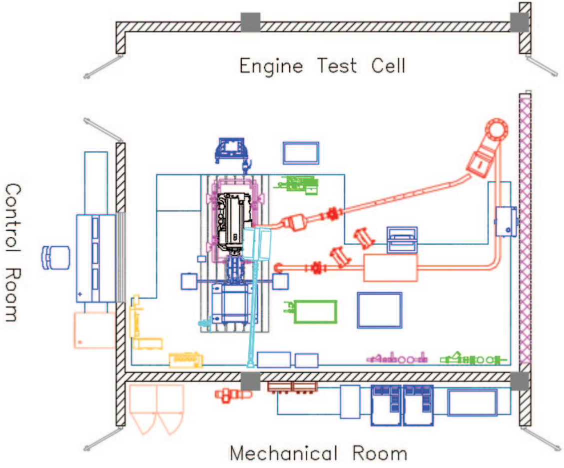
Process Block Diagram

1 CONCEPT | 2 PRELIMINARY DESIGN | 3 DEFINITIVE DESIGN | 4 DETAILED DESIGN | 5 PROCUREMENT | 6 REALIZATION

Core Objectives	Key Tasks	Input requirement	Typical deliverables	Information Exchange	Equivalences
• Prepare definitive design including proposals for structural design, building service systems, outline specifications and cost information • Apply for planning permission • Allow the Client to prepare technical specifications for tenders or approach local sub suppliers	• Follow up workshops with the Customer • Communication with local authorities (if applicable) • Initiate process for tendering & contracting (if applicable) • Discussion with local designers • First approach to possible subcontractors	• Feedback of Phase 2	MASTER PROJECT • Definitive Project report with outline specification of the building and utility service systems • User requirement specifications • Definitive Site Plan • Definitive Building Layout • Utilities Process Diagrams • Utilities layout • Test cells layouts • General time schedule (Weekly basis) • Investment plan • Environmental Impact Study • Risk Assessment • Draft BOM	• Corresponds to the principal input that the local design will get to develop detailed design drawings	• BIM: 2 • RIBA: Phase 3 • US: LOD 200 • HOAI: Phase 3



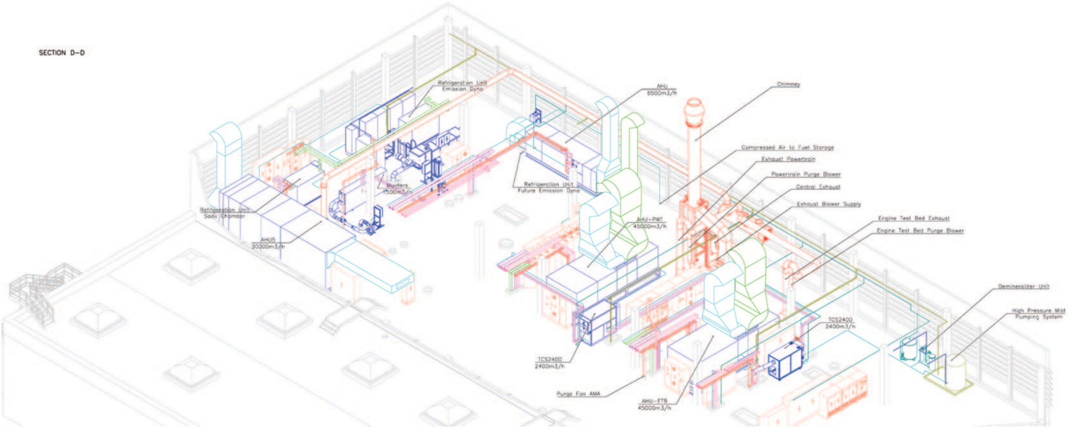
Utilities Process Diagram



Test Cell Layout

1 CONCEPT | 2 PRELIMINARY DESIGN | 3 DEFINITIVE DESIGN | 4 DETAILED DESIGN | 5 PROCUREMENT | 6 REALIZATION

Core Objectives	Key Tasks	Input requirement	Typical deliverables	Information Exchange	Equivalences
• Prepare updated proposals for structural design, building service systems, outline specifications and cost information	• Start-up workshop with Customer. • Definition of key contractual packages • Preparation of the Detailed Design for construction • drawings and specifications in accordance with trade discipline and required by the time schedule. • Attend Project Meetings with the Customer and consultants • Scheduling and coordination with: • Architect. • Environmental consultant. • Health & Safety consultant. • All other consultants as required.	• Feedback of Phase 3	MASTER PROJECT • Architectural Package Master Plan drawing Plan views Test area details • Civil works package Foundations Concrete and Structures Plumbing Mechanical • Process Utilities Process & Instrumentations diagrams Equipment layout Technical specifications	• Not Required	• BIM: 3 • RIBA: Phase 4 • US: LOD 250/300 • HOAI: Phase 5



Process Utilities - Equipment Layout

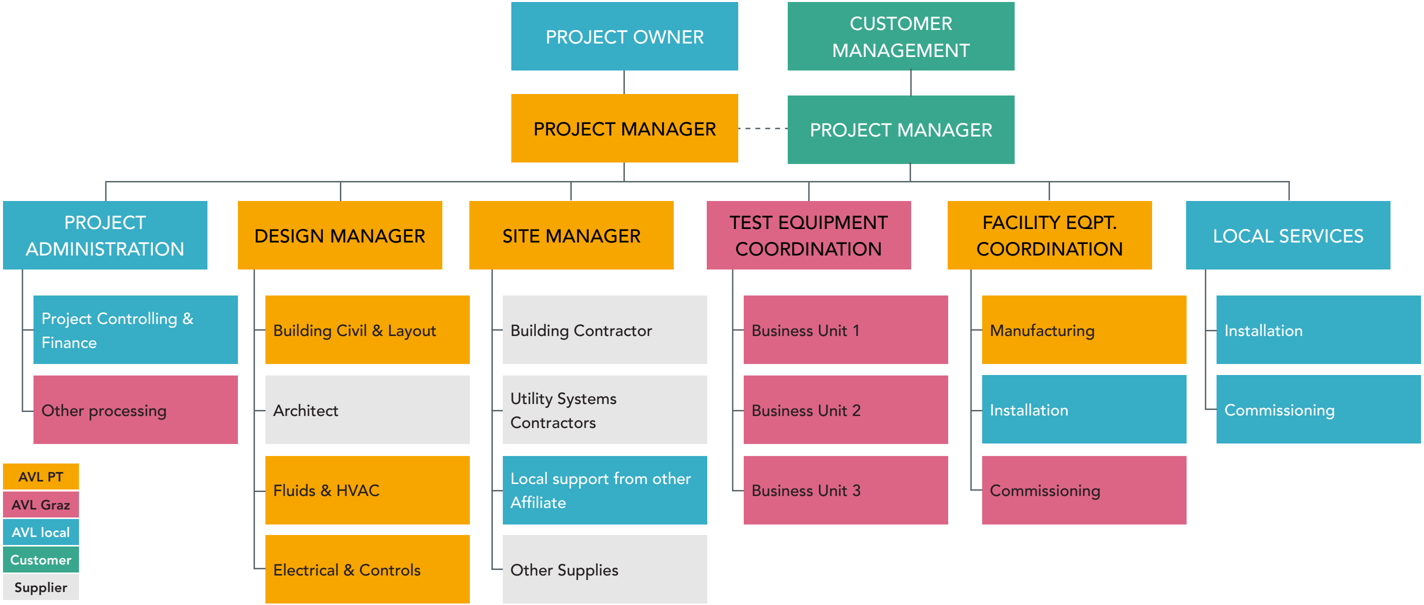
1 CONCEPT | 2 PRELIMINARY DESIGN | 3 DEFINITIVE DESIGN | 4 DETAILED DESIGN | **5 PROCUREMENT** | 6 REALIZATION

Core Objectives	Key Tasks	Input requirement	Typical deliverables	Information Exchange	Equivalences
• International procurement for the most suitable equipment/material at the most competitive conditions • Develop and implement detailed local procurement strategy, logistic plan and control procedure • Initiate construction and supply according to the project implementation schedule	• Edition of purchasing conditions (if applicable) • Bidding procedure (if applicable) • Assistance to Customer for subcontractor selection and evaluation • Edition of contract agreement with subcontractors • Expedite procurement through constant contact with vendor • Plan for inspection, status monitoring, port clearance and transportation activities • Carry out inspection, test and examination, as required and prepare proper documentation (if applied)	• Feedback of Phase 4 • Selected suppliers relevant information • Customer acceptance tests requirements • Agreed purchasing conditions	PURCHASING DOCUMENTS • Tender/procurement Packages, including • Technical Package • Drawings, specifications, standards, test acceptance procedures • Commercial Packages • Corporate Purchasing T&C • Supplier/Quote evaluation reports • Purchasing Contracts	• Not required	• BIM: 4 • RIBA: Phase 5 • US: LOD350/400 • HOAI: Phase 6

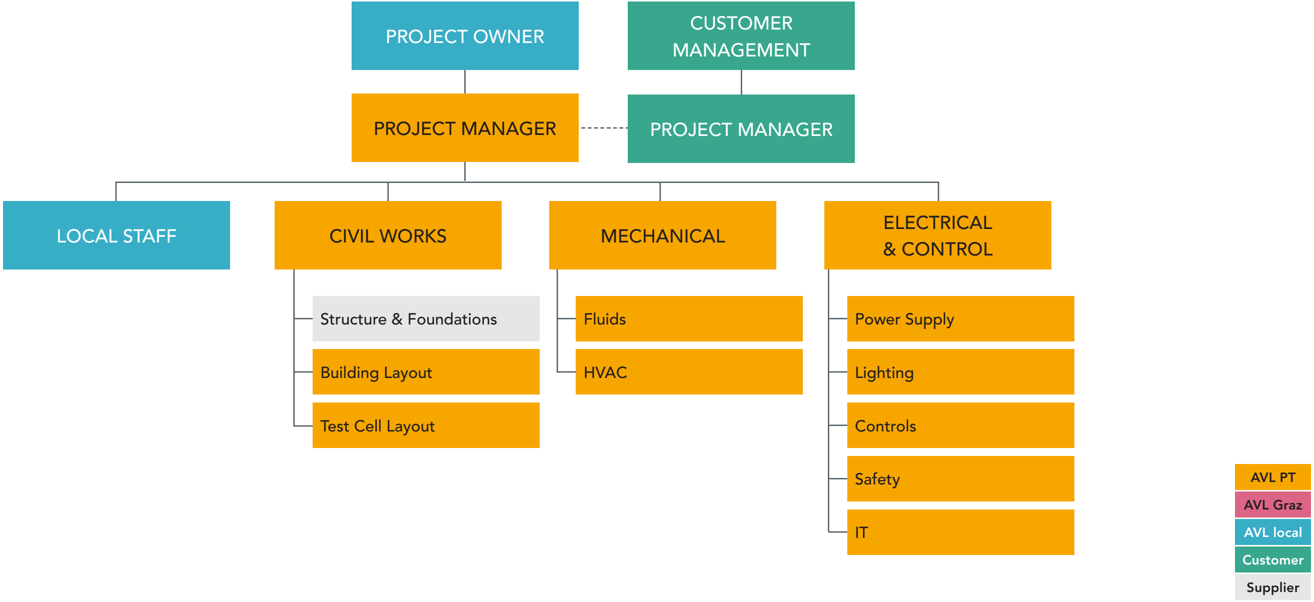
1 CONCEPT | 2 PRELIMINARY DESIGN | 3 DEFINITIVE DESIGN | 4 DETAILED DESIGN | 5 PROCUREMENT | 6 REALIZATION

Core Objectives	Key Tasks	Input requirement	Typical deliverables	Information Exchange	Equivalences
• Offsite manufacturing and on-site construction in accordance with the construction plans. • Resolution of design issues frorm site as they arise • Collecting of technical information to carry out the contracts of temporary utility connections • Handover of building and conclusion of building contract	• Start-up meeting with Customer and subcontractors • Site preparation for construction start • General site mobilization	• Contracts with suppliers • Site clearance to begin with the works • Construction license • HSE kick-off meeting	PROJECT EXECUTION PLAN • Management Plan • Organisation/Communication Chart • Time schedules • Safety Plan • Change orders	• Not required	• BIM: 5,6 • RIBA: Phases 6,7 • US: LOD 400/450/500 • HOAI: Phases 7,8,9

Turnkey Project Organization



Facility Engineering Project Organization



AVL Facility Equipment Catalogue

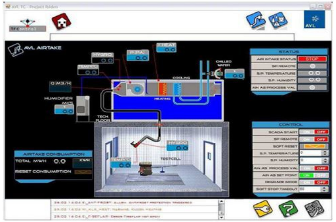
airTAKE
1500 / 2500 / 5000

AVL TEMPERATURE AND HUMIDITY CONTROL OF ENGINE'S COMBUSTION AIR

airTAKE 1500 / 2500 / 5000

As it is well known, the influence of temperature and humidity in the combustion air burned by an engine is a matter of great importance. An increase of 10°C produces a 5% power loss.

Another two important parameters like NOx emissions and knock limit are influenced by humidity.



AVL airTAKE SCADA's interface

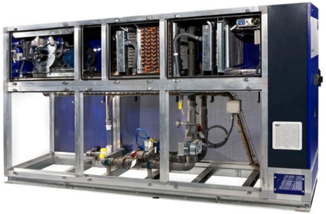
The system is designed to quickly react to any sudden changes of the atmospheric conditions outside the testing facilities or the testing environment inside the test bed.

The structure of the units is made of aluminum. The upper and side panels are insulated and the lower section is covered with perforated metal plates.

The AVL airTAKE is delivered with high standards of quality and performance, and designed with interfaces to be properly integrated in the test bed automation systems.

AVL offers this intake air conditioning unit in 2 different versions with three different versions:

- airTAKE 1500 max. air flow rate 1500 [m^3/h]
- airTAKE 2500 max. air flow rate 2500 [m^3/h]
- airTAKE 5000 max. air flow rate 5000 [m^3/h]



AVL airTAKE side view

Configuration

Complementing the base unit, AVL offers two additional option to comply with the client's request:

- Option P: Preheating Option. It is recommended whenever uncleaned air can be sucked into the test bed at the place the device is installed

- Option H: Humidifier system is integrated together with the airTAKE

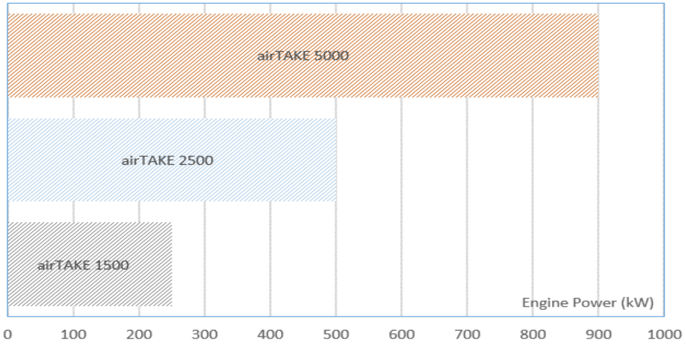
Benefits at a glance

- Compact AHU including automation and control system
- High control flexibility specifically designed for engine test cells
- Minimum installation time both electrically and mechanical
- Minimum commissioning times
- Well tested components and automation system at AVL workshop before delivering to customer

Main features

- A wide range can be provided from 1.000 up-to 5000m^3/h
- Temperature and humidity control
- Antifreeze coils protection to avoid freezing water inside the AHU
- Easy interface with Test Cell Safety System with several digital inputs fire detection or leakage of hazardous gases (CO/HC)
- Supervisory Control and Data Acquisition (SCADA) AVL TFControl

Unit selection



Engine power range covered by AVL airTAKE

airTAKE 1500 / 2500 / 5000

airTAKE		airTAKE 1500	airTAKE 2500	airTAKE 5000	Units
Ambient air conditions at the unit's inlet	Temperature		5 to 40		°C
	Temperature (option P)		-10 to 40		°C
	Humidity		1,5 -15		g H_2O / kg dry air
Cooling water supply (20% glycol)	Temperature		2 ± 1		°C
	Mass flow	6.500	10.000	16.000	kg H_2O / h
	Power	30	45	90	kW
Adjustable air temperature range	min.		15		°C
	max.		40		°C
	Accuracy		+/- 1		°C
Adjustable humidity (option H)	min.		7		g H_2O / kg dry air
	max.		13		g H_2O / kg dry air
	Accuracy		+/- 5		% HR

smARTair
10 / 20 / 30 / 50

AVL MODULAR VENTILATION SYSTEM

smARTair 10 / 20 / 30 / 50

AVL has designed a modular ventilation system specifically aimed to satisfy all possible requirements from automotive testing facilities, going from high accurate control to energy saving requirements.

Every testing facility has its own requirements; the modular ventilation system is designed to fulfill them all regarding air handling.

AVL smARTair 30 fans

The following facts must be taken into account:

- Testing Results: The temperature of some specific parts of the engine have direct influence in testing results; bad control of the ventilation system could produce unreliable data
- Safety: In order to avoid explosive or hazardous atmospheres a good air flow circulation through the room must be ensured. The quick reaction of the ventilation system in case an alarm is detected represents an important difference in safety measures

Configuration

Every testing facility has its own requirements; the modular ventilation system is designed to fulfill them all regarding air handling.w
The standard unit is equipped with three regulation flaps for the fresh air inlet, mixing and extraction sections.

- Option He: electric heating coil
- Option F: integrated fire flaps
- Option O: outdoor installation

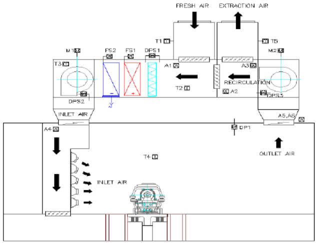
Benefits at a glance

- Low maintenance and Easy-to-operate
- The ventilation system is manufactured and assembled completely at the AVL workshop
- Short installation time
- Remote assistance
- Energy consumption optimization

Main features

- Cooling coils: The installation of a water cooled coil is offered as an option
- Heating coils: required if the unit is placed in a location with Tª< 5ºC
- Inlet air flow control: possibility to control the inlet air flow for additional testing modes
- Negative pressure control for safety
- Antifreeze protection
- Supervisory Control and Data Acquisition (SCADA) AVL TFControl

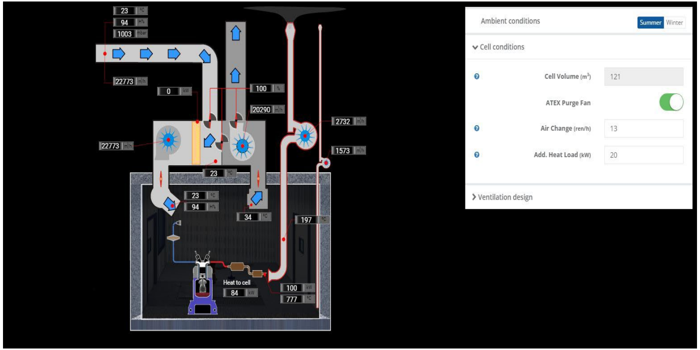
AVL smARTair filters and actuators



AVL smARTair system schematics

Unit selection

AVL Engineering Tool allows sizing the Test Cell ventilation system to its requirements, by introducing desired inlet and outlet temperatures, desired air flow and renovations per hour or the volume of the Test Cell, among other parameters.



SCADA's interface for test cell ventilation sizing

smARTair 10/ 20 / 30 / 50

smARTair Technical Specifications		smARTair 10	smARTair 20	smARTair 30	smARTair 50	Units
Cooling coil capacity (Option CW)	Nominal	120	225	325	600	kW
Heating capacity (Option He)	Nominal	70				kW
Heating capacity (Option Hw)	Nominal	100				kW
Installed electric power	Inlet fan motor	5	11	15	30	kW
	Outlet fan motor	5	11	15	30	kW
	Heating coil (Option He)	70				kW
	Others	2.5				kW
Cooling water supply (Option CW)	Temperature	2 / 7				°C
	ΔP (drop of pressure)	1.5				bar
	Flow	20	45	65	100	m^3/h
Heating water supply (Option Hw)	Temperature	50 / 70				°C
	ΔP (drop of pressure)	1.5				bar
	Flow	5				m^3/h

boostBLOWER

AVL INTERCOOLER AIR REFRIGERATION SYSTEM

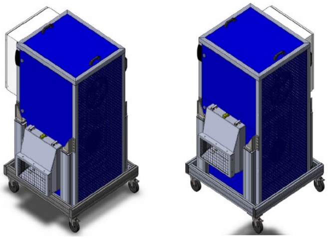
boostBLOWER

AVL boost BLOWER is a compact portable unit, designed to refrigerate the engine's intercooler inside a testbed by simulating wind speeds up to 200 km/h.

The unit is designed to be integrated into an Engine Testcell to minimize the footprint and can be commanded
either in Manual mode or in Remote by an external automation system.

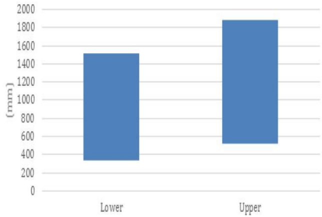
Options

- Electrical cabinet position: this option does not affect the performance of the unit, simply optimizes the space in the testcell accordingto the needs demanded by the customer. This option must be chosen at order



AVL boostBLOWER Option Left and Back

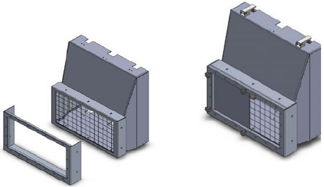
- Nozzle height coverage: the different device fan and nozzle position varies the output height. The range where the device can be used it is also depending how the fan and nozzle is mounted within the unit. By default the fan is mounted to get the range shown below in the lower possible height (option left)



Range covered by AVL boostBLOWER Option Lower/Upper

- Nozzle: short or long versions available. The pressure drop depends also on nozzle length

- Restriction air sliding plate: regardless of the choices above, it is possible to place a restriction at the exit of the nozzle, which reduces the output area to simulate specific cooling over certain engine parts



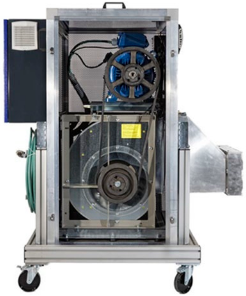
AVL boostBLOWER Option R frame/sliding plate

Benefits at a glance

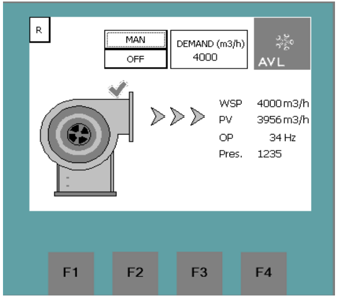
- Compact blowing unit Including Automation and Control System
- High control flexibility specifically designed for engine test beds
- Manually operated or connected directly to the test bed automation system
- Quality assurance. Well tested components
- Accurate flow control
- Flexible outlet configuration for different engine intercooler layout

Main features

- Electronic height adjustment with front control panel
- Maximum speed of 200 km/h
- Air flow measurement through a differential pressure sensor which can provide an analogue signal to an external controller
- Open loop mode, where external automation system controls directly the frequency converter
- Closed loop mode, where the system achieve a predefined flow rate using its internal flow controller
- Nozzle exchangeable to increase flexibility
- Manual operation by means of a touch panel in front of electrical cabinet or remote operation through hybrid interface



AVL boostBLOWER side view



Touch panel on control cabinet

boostBLOWER

boostBLOWER Technical Specifications			Units
Adjustable air speed	40 - 200		km/h
Working temperature	5 to 35, indoor operation		°C
Installed electric power	22		kVA
Power supply (3NPE)	380 - 415 / 50 - 60		VAC / Hz
Power consumption	19		kVA
Device main switch	32		A
Nozzle Output	400x200		mm
Physical dimensions	Length	1185	mm
	Width	995	mm
	Height	min. 1.562	mm
		max. 1.972	mm
	Mass	ca. 380	kg

battBOX

AVL ENGINE STARTING SYSTEM PLUS INTEGRATED ALTERNATOR LOAD UNIT

battBOX

AVL battBOX is a stand-alone and self-contained system that provides you an easy way to reproduce real engine start conditions with the possibility of simulating also a variable load for the engine alternator (option A).

The system includes compartments to place two car batteries 12VDC, one is loaded by an electronic battery charger while the other is used for starting up the engine. A system will switch condition when the used battery is getting empty.

Options

- Option A: external alternator Load Unit. AVL battBOX mounts in the backside of the electrical box an 800W electronic alternator load
- Option EB: external 12V connection box. Standard connection box for being placed near the engine to distribute battBOX power signals to ECU
- Option P: profibus interface. Module attached to the PLC to be communicated to external automation system

Benefits at a glance

- Compact unit,small footprint
- Optimize the batteries life by means of PLC controller
- Power supply rated 30A, 12-15V output manually adjustable for ECU supply
- 12V Battery connection socket for supplying accessories
- Interface hybrid connection to command the functions from an ext. TestCell Automation system
- Comfortable operation for maintenance

AVL battBOX electrical cabinet

battBOX Technical Specifications			Units
Adjustable air speed	1x30	Ignition	A
	1x30	Direct	A
	1x30	Start	A
Max. Power 12 VDC stabilized		30	A
Max. Heat release (with / without Option A)		1040 / 240	W
Profibus DP Slave speed (Option P)		19.2	kbps
Battery Charging capacity	Range	40 - 200	Ah
Alternator Load current (Option A)		60@13.5	A@VDC
Operating Voltage		1 ~ 220 - 240	VAC
Operating Frecuency		50 - 60	Hz
Environmental conditions	Temperature	-10 to 45	°C
	Humidity	1.5 - 15	g H_2O /kg
Physical Dimensions	Length	594	mm
	Width	365 (694 with open box)	mm
	Height	1.250	mm

Container Test Bed

TURNKEY CONTAINERIZED ENGINE TEST FACILITY

Containerized Test Beds, Test Bed Modules can be used for nearly every Engine Test Bed Application such as:

- Durability
- R&D
- EOL
- QA
- HD or LD certification

The Test Bed Modules are also used for Electrification Application such as:

- Battery Testing
- E-Motor Testing
- Converter Testing

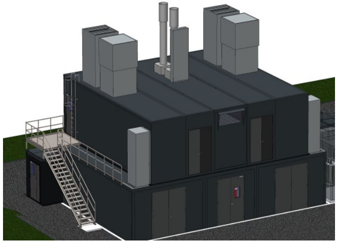
Test Bed Modules are suitable for any kind of environment and can be installed indoor or outdoor.

The related measurement equipment such as emission benches will be also placed in modules

For achieving the most flexible usage not only the Test Bed and specific measurement equipment can be modularized, also the related utilities can be set-up in modules which are placed either on top of the Test Bed modules or next to it.

Main dimensions are 7 x 5 x 3.5m (L x W x H), whereby an internal height of approx. 2,85m is available.

The walls and roof of the containers are of panel construction providing ½ hour fire resistance and sound attenuation.



Container Test Bed

Benefits at a glance

- Realization time shortened by up to 6 months (compared to approx. 18 months for conventional 10 test cell facility
- Increased flexibility is achieved by slightly reduced costs
- No special legal requirements, therefore simplified approval procedures
- Reduced financing costs
- No technical floor required
- High efficiency from the very beginning

Main features

- Standardised Test Cell Components for 4 power classes (150/250/350/450kW)
- Standardised Utility Modules for 4 power classes (150/250/350/450kW)
- Standardized modules for optimized production
- Weather-proof solution for outdoor installation
- Low noise level
- Modules designed for easy maintenance

Contact Information

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