CIMAC CONGRESS 25
ZURICH, MAY 19 – 23, 2025

2025 | 363

ACCX300-L axial turbocharger series development update

Turbochargers & Air/Exhaust Management

Simon Ma, Accelleron Industries

Franco Domenig, Accelleron Industries
Peter Hönisch, Accelleron Industries

ABSTRACT

The timeline to meet maritime emissions goals continues to accelerate the IMO ambition to reach net-zero close to 2050, well-to-wake. Along with new emission regulations being introduced, various stakeholders (regulators, financiers, consumers) continue to exert pressure on shipping companies demanding more action to be taken to decarbonize. This drives also accelerated product development cycles for the next step in efficiency gains. Technology flexibility and future viability of assets becomes ever more important.

Accelleron development activities are focused on supporting the flexibility and future viability of two-stroke engines. At the core of these activities is the realization of the next generation of axial turbochargers, named the ACCX300-L series (X300-L series), which will replicate the superior performance capability and reliability of Accelleron's current generation of low-speed turbochargers and thereby satisfy the requirements of two-stroke engines today. In addition, we take a next step in specific flow capacity, enabling innovative service concepts and providing tangible fuels savings with added flexibility in the context of decarbonization.

This paper provides an update on the development progress being made, as well as describing some of the tools and methods used to qualify the new design and verify performance. Also included is an account of the key concepts enabled by the design features. Such concepts include turbocharger cut-out to maximize part load operation of the engine for both new vessels and the existing fleet, TWIN driving value with multiple turbochargers of smaller and lighter parts, and cartridge exchange enabling greater operational flexibility and lifecycle optimization opportunities when in combination with digital monitoring.

Understanding the importance of future fuels to emissions reduction efforts, Accelleron has made and continues to make notable efforts to assess the compatibility of materials used in its portfolio of turbochargers in anticipation of two-stroke and four-stroke engines' transitioning to such fuels. An investigation into the impact of ammonia rich gases on turbocharger materials is summarized. The results and subsequent conclusions show that under the currently anticipated turbocharger operating conditions, the use of ammonia as fuel poses a low risk for Accelleron turbochargers including the much anticipated X300-L series for two-stroke engines.

1 INTRODUCTION

Considering the level of ambition and current progress made, to achieve emissions targets, an accelerated pace of innovation is needed [1], [2], [3]. This implies for technology providers not only an adaption to the way products are developed but also with each development relatively big steps in efficiency. For Accelleron's next generation of axial turbochargers, core components were developed, and feasibility of key turbocharger sub-systems investigated ahead of product development. This gave designers more freedom to make a significant innovative step and with much more confidence knowing that once product development started, the technology would go to market with requirements met and on time.

In 2023, development of this next generation of axial turbochargers was announced [4] that reflects the outcome of this approach. The targets being to:

- Meet the requirements of today's 2-stroke engines and the low-pressure stage of a 2-stage turbocharger system for 4-stroke large bore engines
- Take a platform approach that maximizes commonality of components, minimizing variants and standardizing engine interfaces to reduce supply chain complexity and create additional design freedom
- Take advantage of that extra design freedom and make a next step in power density, maximizing coverage with less frame sizes than today without sacrificing the high performance expected from Accelleron in the low-speed market
- Include a more modular approach, such as an easily exchangeable cartridge containing all rotating parts as an enabler for innovative service solutions
- Enable more opportunities for tangible fuels savings and added flexibility in the context of decarbonization with more turbochargers of smaller and lighter parts

In this paper an update of the development progress is presented, elaborating on the technical features of this new turbocharger series and touching on some of the tools and methods used to qualify the design and verify performance. The concepts made possible by these technical features are also highlighted, one concept specifically is turbocharger cut-out to maximize part load operation of a 2-stroke engine and extending the benefits of such a system to the existing fleet via Accelleron's own solution, FiTS2.

Understanding the importance of future proofing assets considering the introduction of future fuels [5], Accelleron has also made and continues to make notable efforts to assess the compatibility of materials used in its portfolio of turbochargers in anticipation of the transition to fuels such as methanol, ammonia, and hydrogen. Included as well in this paper is a summary of an investigation into the impact of ammonia rich gases on turbocharger materials.

2 ACCX300-L TURBOCHARGER SERIES

This next generation of axial turbochargers for 2-stroke engines is Accelleron's ACCX300-L (or abbreviated verbally as "X300-L") turbocharger series to follow in the successful footsteps of the current A100-L and A200-L series for 2-stroke engines.

Development is now well underway with the procurement of prototype parts and an extensive qualification programme. The starting frame sizes in development are ACCX365-L and ACCX370-L. The following section goes into some of the details of the compressor and turbine development which play a major role in taking this next step in power density and performance.

3 COMPRESSOR DEVELOPMENT

For the new axial turbocharger generation, the following three targets of the compressor development were defined:

- Leap improvement in power density through increased specific volume flow rate
- Compressor map width optimization providing full flexibility of turbocharger operation for 2-stroke and 4-stroke applications
- High efficiency at part load and at full load points up to pressure ratio 5.0 enabling the optimum turbocharging solution for every application of the broad range of the target engine portfolio

3.1 Improvement in Power Density

Core target of the compressor development for the new turbocharger generation is a significant increase of power density to sustain the market position as presented in [4]. At the same time, the compressor map range is extended from pressure ratio πC, of 4.8 up to above 5.0, enabling engine builders the next steps in increasing mean effective pressure. Naturally, the development focused on the key value of unchanged high efficiency levels for the entire compressor operating envelope.

The improvement in power density is shown in Figure 1. Therefore, the compressor's specific volume flow rate (Eq. 1) could be increased by more than 20%.

Specific volume flow rate = $\dot{V}_{298}/D_C^2$ (1)

Equally focused on performance and reliability this next step in power density is made whilst also covering the exchange intervals of 100'000 running hours expected in 2-stroke engine merchant marine applications. Equivalently, exchange intervals of 80'000 running hours can be ensured for large bore 4-stroke marine and base load power plant applications.

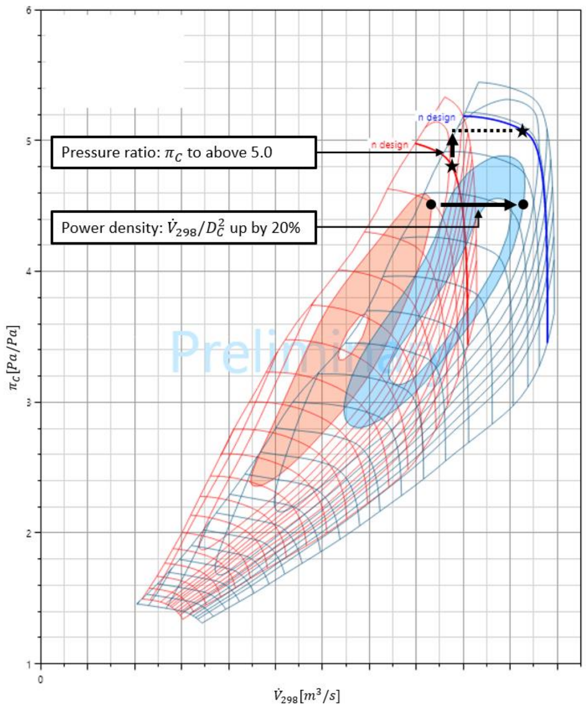

Figure 1. Compressor map extension for full load operation point at an exchange interval of 100'000 running hours; compressor pressure ratio vs volume flow

3.2 Compressor Map Optimization

Stable operation of the engine requires sufficient margin of the operation line towards the compressor surge line. Compressor stability becomes a special focus when compressor pressure ratio and specific volume flow rate are increased as implemented for this new turbocharger generation. Applying up-to-date map width enhancement technology as described in [6] enables to reach optimal compressor performance for the targeted range of pressure ratio. Accordingly, an increased pressure ratio from 4.8 to above 5.0 can be provided compared to the A200-L reference stage.

Key to achieving robust compressor maps in new turbocharger series covering this next level of power density and pressure ratio is physical verification of the final product. Therefore, the sensitivity of the new compressor stage to the various impacts from design specifications as well as outside interfaces was tested in the ACCX370-L turbocharger frame size, utilizing Accelleron's unique test rig facilities.

The findings from testing enabled to enhance the compressor stage design while using established CFD analysis methods in parallel. The important step in the development process was applying a multi-objective optimization approach.

Accordingly, compressor efficiency was maximized numerically at part and full load on the one hand. On the other hand, the characteristic of the dimensionless static pressure rise (Eq. 2) was applied as well-approved stability criterion as documented in [7].

$$Dp = \frac{\Delta p}{\rho_E u_2^2/2} \qquad (2)$$

Using CFD simulations, the characteristics of the full compressor stage as well as the subcomponents shown in Figure 2 were calculated for the compressor maps critical surge boundary of each resulting design iteration.

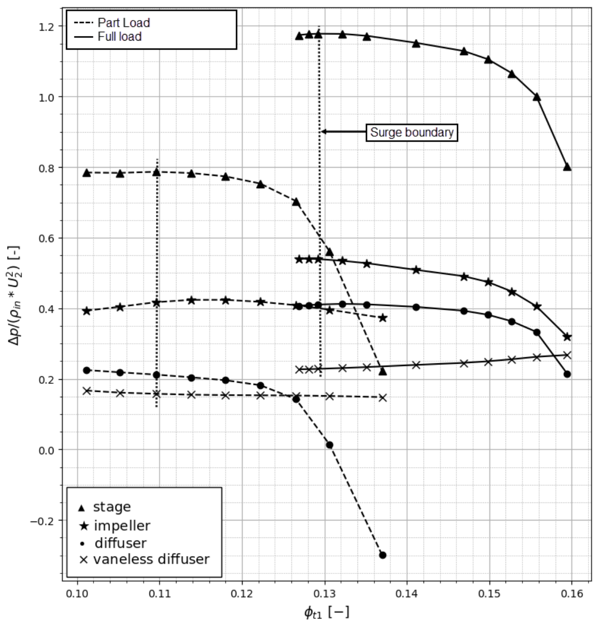

Figure 2. Example for characteristics of complete compressor stage and related subcomponents

The gradient of the subcomponents pressure rise characteristic was then optimized with respect to stability at part and full load. Therefore, the combination of impeller, diffuser, volute and map width enhancement devices dedicated best to the targeted performance level could be identified.

Beyond thermodynamic performance, mechanical integrity as a demanding market requirement was continuously assessed within the compressor development through integrated FE computations. Therefore, fulfilling Accelleron's rigid qualification processes through physical confirmation on turbocharger test rigs can be ensured for the new compressor stage's reliability regarding high cycle as well as low cycle fatigue.

3.3 Flexibility in Compressor Efficiency

The target of the new turbocharger generation was to integrate compressor specifications for 2-stroke and 4-stroke (low-pressure stage of a 2-stage turbocharger system) applications respectively within one concept.

The requirements regarding efficiency, pressure ratio and compressor map width are completely ensured through a modular concept of compressor stages available for each turbocharger frame size.

Therefore, compressor stages optimized for the specific volume flow range are fitting into a single compressor casing and share the same shaft connection. The implemented compressor efficiency in relation to the current turbocharger generation A200-L is depicted in Figure 3.

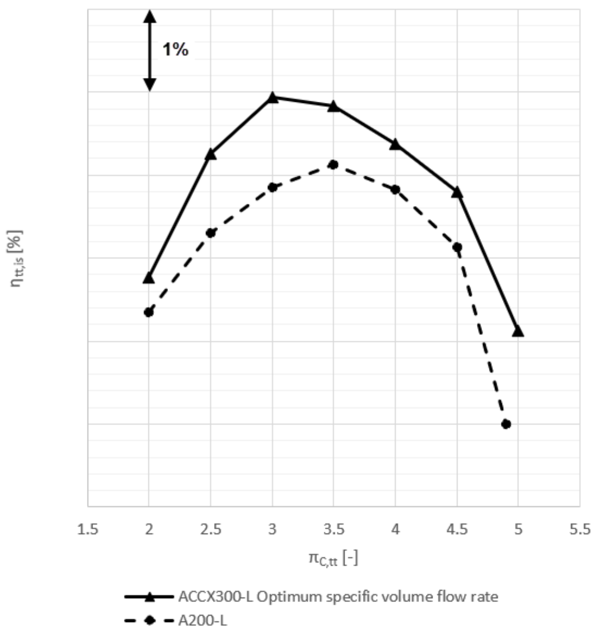

Figure 3. Compressor efficiency along operation line for ACCX370-L in comparison to A200-L

The new ACCX300-L turbocharger generation enables pressure ratio 5.0 for the complete compressor portfolio providing the required efficiency level as shown in Figure 3. At the same time, a further increased efficiency level compared to the current A200-L compressor can be ensured with the optimum specific volume flow rate stage for a large range of the turbocharger applications. For the remaining high specific volume flow rate specifications, the required turbocharger efficiency can be ensured through the optimum compressor–turbine matching.

Figure 4 visualizes the application range of the new ACCX300-L turbocharger series. The compressor map coverage reveals especially the simplification and modularity of the new ACCX300-L turbocharger compared to the current A200-L series. Therefore, a maximum flexibility can be provided in terms of specific volume flow rate, pressure ratio and efficiency with the first two frame sizes.

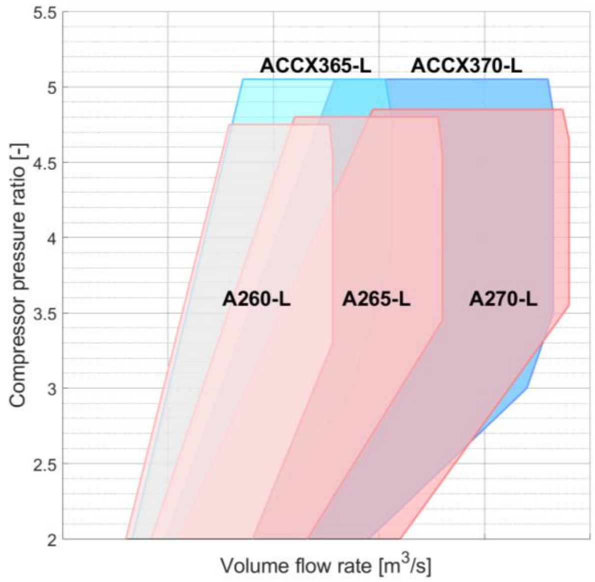

Figure 4. Compressor map coverage ACCX300-L next generation axial turbocharger vs. A200-L

4 TURBINE DEVELOPMENT

An advanced axial turbine stage has been developed to achieve the following key objectives:

- Substantial increase of specific flow capacity and power density
- Significant increase of efficiency level, both at part-load and at high turbine pressure ratios
- Nickel-base alloy integral rotor with proven mechanical durability
- Axial compactness, i.e., reduction of axial length of the turbine stage.

Efficiency and power density goals have been well achieved as already presented in [11]. Meanwhile the turbine passed Accelleron's extended qualification process. Besides the confirmation of thermodynamic efficiency for the entire range of turbine volume flows a focus was set on the verification of mechanical integrity.

Blade vibration testing by means of strain gauge and blade tip timing measurements confirmed the robustness of the turbine stage against high cycle fatigue in normal operation.

In addition, reliability was investigated for operation using turbocharger cut-out operating scheme [11]. For engine load points in which the operation of all turbochargers is required the flaps of the cut-out system are opened. On turbine side the butterfly valve upstream the turbine inlet leads to a disturbance of the flow and potentially to an increased excitation of the subsequent blade row. This excitation potential was systematically investigated for various turbine specifications. For this purpose, a dedicated butterfly valve was used. Its geometry is similar to flap designs of major equipment manufacturers.

During testing several parameters were varied, i.e., distance of the flap to turbine inlet, angular position in piping, opening angle of the flap, Figure 5. The results of testing enabled to formulate a dedicated guideline for the installation of the flaps for turbocharger cut-out operation. Taking this last step, Accelleron's rigid qualification process of the turbine was successfully completed.

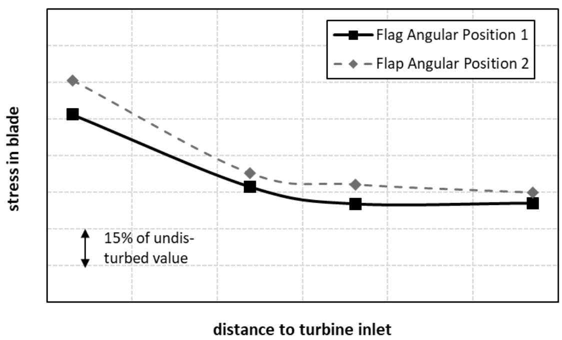

Figure 5. Change in blade vibration amplitude due to disturbance in piping induced by butterfly valve

5 QUALIFICATION

Accelleron has constructed an intensive qualification programme for the ACCX300-L turbocharger series to assess numerous aspects of the different parts in operation including performance, assembly, reliability, safety, and regulatory compliance. The following describes a selection of the topics being assessed, an overview of the methodology and where possible the results.

The mechanical integrity of the different parts in operation is fundamental for the reliability and safety of the turbocharger. Deformations and misalignments during transient and at full load need to be addressed to quantify their influence on the clearances and timely identify corrective actions.

5.1 Thermo-Mechanical Fatigue (TMF) and Creep Assessment

The mechanical integrity and the function of the different static parts of the turbocharger are proven under TMF and creep by means of FE assessments or analogous methods. In this abstract we focus on creep. The components for which creep needs to be analysed are derived from previous turbocharger experience and from the expected temperature profile. The lifetime and deformation due to creep of the different components shall be checked.

Creep assessment was done with simulations using in-house routines for different materials. The boundary conditions were generated with CFD simulations for the ACCX370-L including pressure levels. The pressure pulsations adapted accordingly. For all the parts assessed, both creep strain and deformation were determined.

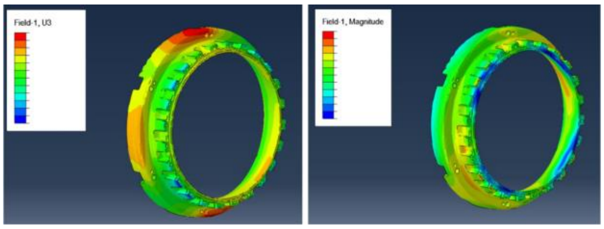

Figure 6. Turbine diffuser creep deformation

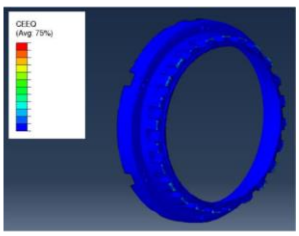

Figure 7. Turbine diffuser strain

Figures 6 and 7 show an example of the results of the deformation and creep strain of the turbine diffuser. The maximum deformation after 36'000 running hours and the creep strain are well within limits.

For all parts assessed, the lifetime and the amount of creep strain was acceptable. From further analysis of the results, compared to design currently released in the field, no relevant different behaviour is expected.

5.2 Turbocharger Vibration Qualification

The mechanical integrity with respect to vibration imposed from the engine to the turbocharger needs to be verified. For this the vibration limits of the most stringent application formed the basis for determining the maximum target velocity and acceleration of the components. Also considered in addition are safety factors as defined by internal guidelines.

The qualification for ACCX370-L was carried out experimentally on an external test rig. The turbocharger was mounted on an adapter plate to a slip table of a vibration test bed and excited with a shaker.

Prior to testing, specific attention was made to checking the geometry, surface discontinuities, surface roughness, tightening torques and positioning of the assembled turbocharger components. Similar efforts were made after testing.

Ten triaxial accelerometers were used and the signals recorded via a data acquisition system, refer to Figure 8.

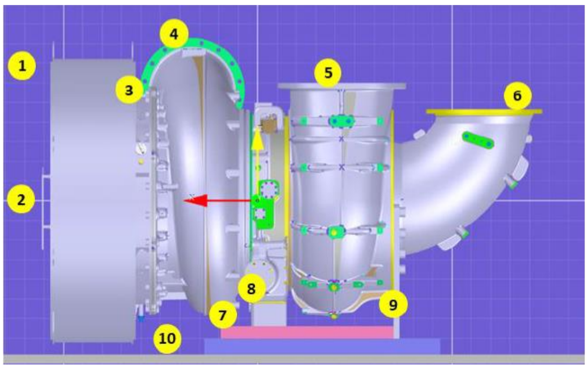

Figure 8: Location of accelerometers for vibration qualification

The test programme included both the identification of the natural frequencies and endurance tests. The resonance identification was repeated after the endurance tests to identify and document changes.

Based on the test results the ACCX370-L can be qualified according to the defined internal protocol.

5.3 Assessment of Filter Silencer Casing Design

Optionally the filter silencer will be enclosed by a filter silencer casing (casing around silencer for external air inlet) to guide the air directly from the outside of the vessel to the silencer. The fundamental shape of the filter silencer casing is based on the well-proven casing design of A100/200-L turbocharger series. The casing will feature a universal design, applicable for all required inlet flange positions.

This assessment is performed both from a fluid-dynamic point of view as well as in terms of aerodynamic excitation potential of compressor blade vibration. Therefore, the objectives of the investigation included the identification of potential regions of flow separation with possible design improvements whilst maintaining good manufacturability. The quantitative influence of those design changes is then assessed on the uniformity of the mass flow distribution at filter silencer inlet and further evaluation of compressor aerodynamic excitation potential.

It is assumed that the non-uniformity of the filter silencer inflow, potential flow separations within the casing as well as the aerodynamic excitation potential of the compressor are amplified as the mass flow rate increases. For the sake of a conservative assessment, the ACCX370-L operating point with highest mass flow rate is accounted for.

Figure 9 illustrates the position of the eight equal-sized sectors used to quantify the non-uniformity of the inflow into the filter silencer. The bar charts depict the relative mass flow share going through the individual sectors with the filter silencer casing optimized. For reference, the relative mass flow share for an ideal uniform inflow distribution is represented by the dashed lines.

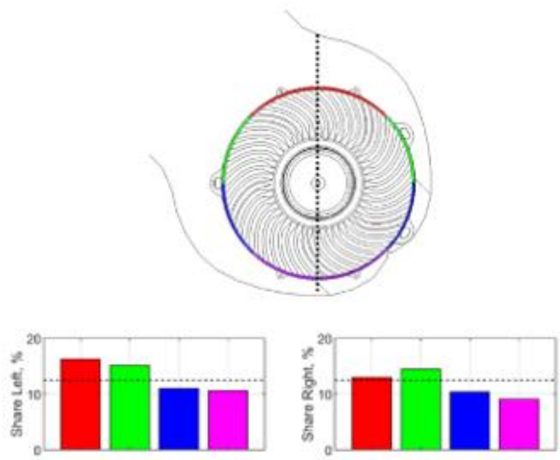

Figure 9: Equal-sized sectors applied for evaluation of mass flow distribution and the relative mass flow share going through each sector

Several recommendations were concluded from the assessment of various designs to reduce tendency to flow separation as well as the intensity of the secondary flow structures developing at specific casing positions.

Non-uniform inflow conditions into the filter silencer casing, induced for example by flow redirections in the upstream piping, might cause flow separations within the casing and adversely affect the filter silencer inflow in terms of its spatial uniformity and with those changes in the aerodynamic excitation potential. To prevent such problems stemming from the installation situation of the casing, it is recommended to define criteria for the upstream piping or criteria for the required flow conditions into the casing within customer documentation.

5.4 Calibration of the Sealing Air System and Measurement of Volumetric Losses

The performance of the sealing air system plays a major role in the oil tightness of the turbocharger and protection of the piston rings against contamination during operation. Knowledge of the volumetric losses of the sealing air system of an axial turbocharger is necessary to correctly evaluate the thermodynamic performance.

The target of this test was to find the best sealing air calibration setup with enough airflow to prevent oil leakage, with least blow-by and air loss to turbine outlet as possible. Several variants of shaft sealing bushes with different outer diameters were tested with ACCX370-L.

The calibration was performed in two stages, the first part to determine the discharge coefficients of the sealing air channels and the second part, measurement of the volumetric losses of the sealing air system on the hot gas test rig, to determine the performance of the sealing air system on the standard operation line.

After testing several variants and conditions, oil tightness was proven during full load operation. Hence a suitable sealing gap between the rotating shaft sealing bush and the static sealing cover was identified and an optimal outer diameter defined.

6 ACCX300-L CONCEPTS

By achieving the development targets a foundation is established from which the X300-L turbocharger series can support both the requirements of 2-stroke engine today and the needs of shipowners and operators in their GHG emission reduction efforts via the following concepts.

6.1 Cartridge Concept

Within the first two frame sizes ACCX365-L and ACCX370-L there is a key design feature, an exchangeable cartridge containing all rotating parts. The cartridge concept, allows the extraction and installation of the turbocharger core without further dismantling to isolate the rotor, as performed during a major service event, see Figure 10.

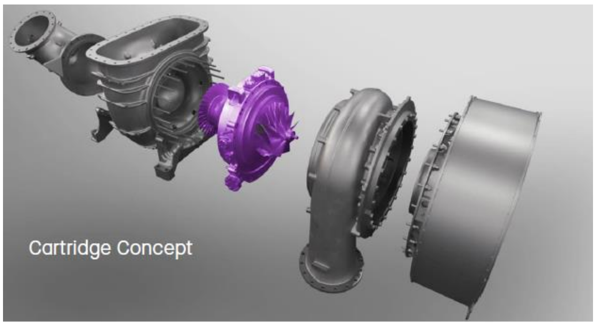

Figure 10. The exchangeable cartridge highlighted

Figure 11 confirms the manufacturability of the cartridge and complete turbocharger assembly. Feeback and recommendations from iterative assemblies will be incorporated into the working instruction and training methodologies, together with the supporting tooling concept for maintenance.

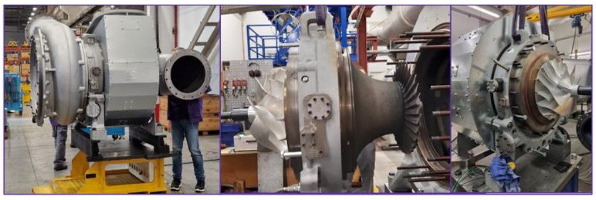

Figure 11. First assemblies of cartridge and complete turbocharger with no major issues.

Special attention was made on the processes associated with removing and installing the cartridge, made simpler from the following:

- The turbocharger can be opened from the “cold” side, without touching the gas inlet and gas outlet casing, as well as both feet
- All casing connections are axially accessible within the box volume of the turbocharger once the air outlet is dismantled
- The cartridge including packaging for transportation are designed to fit on a standard shipping pallet.

The combination of these features maximizes the opportunity to exchange the cartridge, effectively completing a major service overhaul during a port stay by Accelleron service engineers (cartridge removal and installation by the vessel's crew is possible). This is in addition to the traditional dry-docking schedule. In case an exchange of the cartridge is not needed, the turbine can also be dismantled from the "hot" side as known today from the A100-L/A200-L turbocharger series, performed at dry dock.

By combining Accelleron's global service network capabilities and digital monitoring offerings, with a pool of new and refurbished turbocharger cartridges, vessel operators have the key benefit of highest availability and optimal usage of components without the need to invest in own exchange cartridges, see Figure 12.

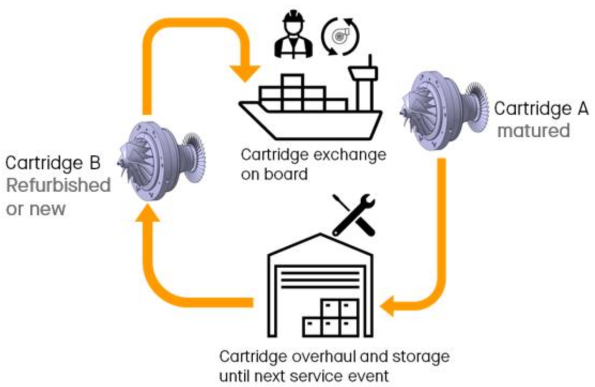

Figure 12. Major service event at port stays from a pool of new or refurbished cartridges.

With a new or refurbished cartridge ready for the exchange, an average turbocharger job duration of approximately 12 hours is estimated. The health of these pooled exchange cartridges is ensured via Accelleron's Turbo Insights and visual inspections in the workshop.

The result of being no longer tied to the dry-docking schedule for maintenance potentially mean less overhaul events over the lifetime of the vessel and thus reduced lifecycle costs. The cartridge concept allows full utilization of components refer to Figure 13. This opportunity becomes even more apparent in the context of turbocharger cut-out, to be elaborated on later in this paper.

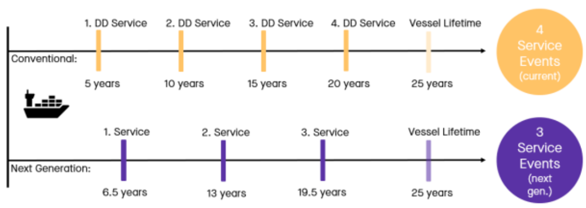

Figure 13. Full utilization of component lifetime resulting in less major service events (Service) versus traditional drydock to drydock (DD Service)

6.2 TWIN Concept

As mentioned earlier a target for the development of this next generation of axial turbochargers is to increase power density. By doing so the benefits of the cartridge concept are extended to the highest engine power range possible for the first two frame sizes X365-L and X370-L and further reduces the complexity of managing a cartridge pool from less variants.

The TWIN concept continues this, with the potential to combine unconventionally in various pairings (referred to here as "TWIN") each of X365-L and/or X370-L, refer to Fig14. This brings the benefits of the cartridge concept to even higher engine power where the cartridge weight, transportation and job duration requirements from larger frame sizes are likely prohibitive.

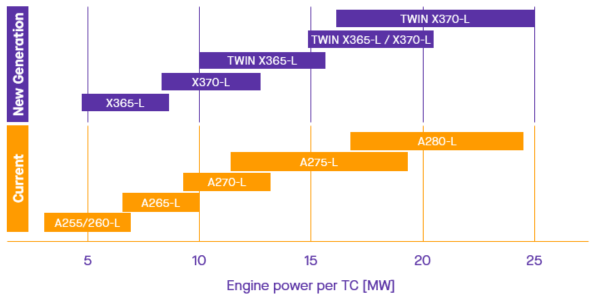

Figure 14. Extension of the cartridge concept to higher engine power

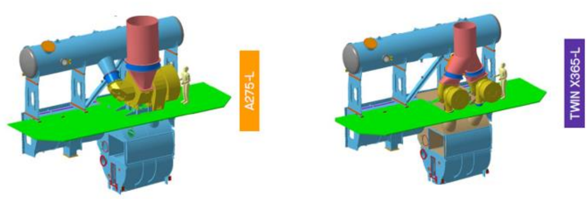

Figure 15. Alterative turbocharger arrangement, 90 degrees to the engine axis

With the possibility to serve higher engine power needs with the TWIN concept (i.e. parallel combinations of smaller and lighter turbochargers) there are advantages with handing of the components, from occupying less space and lower individual lifting requirements. Also creating additional options for on-engine turbocharger arrangement (see figure 15) to accommodate potentially more complex engine configurations and exploiting more opportunities for turbocharger cut-out.

6.3 Turbocharger Cut-Out

Turbocharger cut-out is intended during engine part load operation. By cutting out one turbocharger at lower engine loads higher scavenging air pressure, higher compression ratio and firing pressure are reached resulting in a higher engine efficiency and lower specific fuel consumption. An additional benefit comes from the possibility to switch off the electrically powered auxiliary blowers, and therefore reduced energy consumption.

The benefit of such a system can apply in the following scenarios:

- Majority of the vessel engine's operation time spent at low engine loads, for example a very large container vessel, refer to Fig 16.
- Vessels needing to operate at lower speeds as one of the operational measures with highest potential to reduce CO2 emissions [8].
- Large container vessel with multiple turbochargers as cost of decarbonization is expected to hit containerships harder than tankers and bulkers [1].
- Make the most from running on less energy intensive and costly alternative fuels.

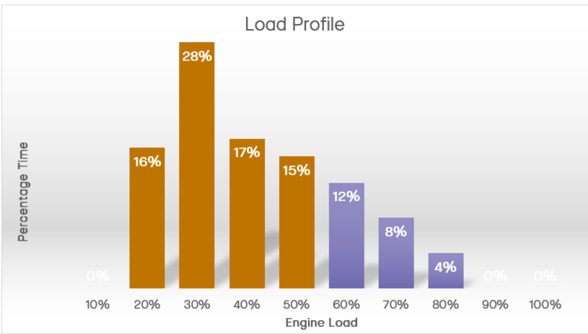

Figure 16. Example load profile of a very large container vessel

X300-L turbochargers are equipped with an external sealing air connection, bi-directional radial bearings and prepared for the cut-out operation.

In the case of turbocharger cut-out, the turbocharger's participating in the cut-out operation will have a different utilization to those that are not, and hence the existence of different maintenance needs for turbochargers on the one vessel. The X300-L turbocharger series leverages its cartridge concept for vessel operators to satisfy these varying maintenance needs with the flexibility of major service events during port stay in addition to dry dock. Also referring back to the full utilization of components mentioned earlier.

7 FITS2: FLEXIBLE INTEGRATED TURBOCHARGING SYSTEM FOR 2-STROKE ENGINES

For the existing shipping fleet, turbocharger cut-out can also be an option to upgrade 2-stroke engines and support achieving reduced costs, meet emission targets and comply with regulations.

To cut-off the inlet gas flow to the turbine and the compressor outlet to avoid backflow, this has been done manually by covering turbine inlet and compressor outlet with plates or valves, possible only at standstill or at very low load points. In some cases, this manual effort is avoided or forgotten.

Accelleron's FiTS2 system provides an integrated turn-key solution without disruption to vessel operation, for fully automated cut-out and cut-in operation via an in-house developed Control Unit interfacing with the engine control. In this way, optimizing the engine fuel consumption at part and low load maintaining at the same time the flexibility to go to full engine output immediately.

In the case of an engine with three turbochargers for a large container vessel, the middle turbocharger is used for the cut-out/in operation. The system consists of a gas inlet and an air outlet "butterfly" valve with pneumatic actuators, a pneumatic skid with back-up bottles and control unit. This control unit is internally programmed and interacts with standard electrical signals to monitor the process states and set the valve positions accordingly. The control logic continuously observes the system for malfunctions and takes appropriate actions.

To minimize risk from inverse rotation of the turbocharger rotor, limit overshoot in speed and surging, the valves are open and closed in a specific sequence and timing.

Operation of the system was remotely monitored via data ingress in Accelleron's Field Data Backend. Data evaluation was based purely on signals already fed to the automation system, no additional signals from the FiTS2 control unit. The evaluation of FiTS2 switching cycles and running hours is based on turbocharger speed comparison between cut-out and non-cut-out turbochargers. The benefits of such a system are shown below, before application of FiTS2, Figure 17 and then with the FiTS2 system, Figure 18.

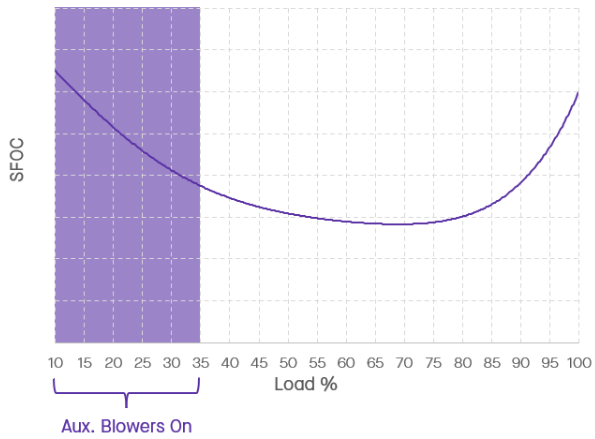

Figure 17. Prior to the application of FiTS2, specific fuel oil consumption versus engine load %.

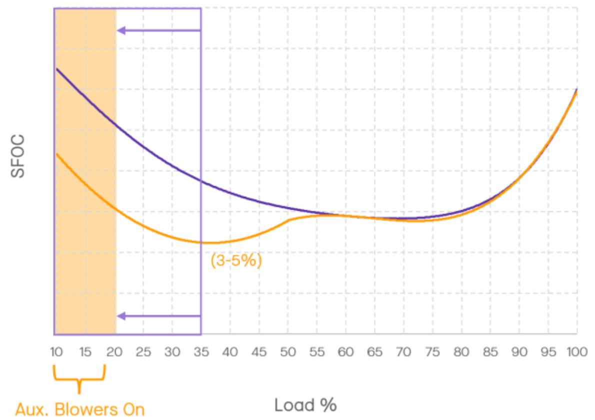

Figure 18. Example of turbocharger cut-out at 60% engine load, fuel savings of 3-5% and optimized auxiliary blower switching point.

With respect to product safety and reliability, turbocharger containment qualification remains valid, as malfunction of the FiTS2 system does not impact the turbine burst speed. The butterfly-valves are designed for so called fail-safe "Open" mode, which means that in case of disturbance, mismatch or safety function is detected, both valves move to "Open" position. This is ensured even during loss of electrical power. In case of loss of pneumatic air supply there are two air-bottles installed on the pneumatic skid, which ensures that the air supply for a fail-safe operation is at all times ensured. Periodic valve movement was implemented to prevent a valve from getting stuck and or excessive deposit accumulation near the valve area.

At the time of writing this paper, the system had performed over 95 cut-out cycles and 800 hours of operation in cut-out mode without any major issues.

8 CORROSION EVALUATION OF DIFFERENT ALLOYS AND ELASTOMERS IN AMMONIA RICH ENVIRONMENTS

Accelleron has made several studies into the potential impact of alternative fuels on turbocharging requirements [15, 16, 17]. As an alternative fuel, methanol is already established in the low-speed engine market according to the Diesel cycle and thus field experience exists. However, the same cannot be said for Ammonia, so further understanding not just of the fuel properties and feasible combustion concepts, but also the impact of the fuel on applied materials.

The following summarizes an investigation aimed at testing the corrosion performance of different alloys and the performance of rubber materials in various ammonia rich gases containing different proportions of O2, N2, Ar, H2O, NH3 and temperatures ranging from 50degC to 345degC. The test was conducted in autoclaves and glass kettles at a pressure of 4bar with standardized material coupons of same dimensions and surface finish.

The exposure test was conducted for 30 days without interruption. At the end of exposure, the coupons were removed, cleaned and the weights before and after exposure were obtained. Visual and optical examination were conducted after exposure to determine the degree of corrosion. The exposure tests were conducted in triplicate for each material type and in duplicate for the rubber materials

The investigation demonstrated that all the coupons exposed to ammonia-rich gases did not exhibit uniform corrosion of the surface. Rather, corrosion was mostly localized in the form of pitting corrosion. Average pitting rates show pitting corrosion is considered low risk for localized corrosion for all the cases per NACE SP0775-2013. The results of the metallic coupons showed no statistical difference between the pre- and post-weights, denoting negligible uniform corrosion rate for all the cases.

For specific rubber materials, there was a noticeable weight loss after exposure, in the case of two specimens an entire break through the cross section. This weight change for the elastomeric materials is a result of physical and chemical interactions between the elastomeric macromolecules and the solution. Figures 19, 20 and 21 show the representative pictures of the cleaned coupons after exposure.

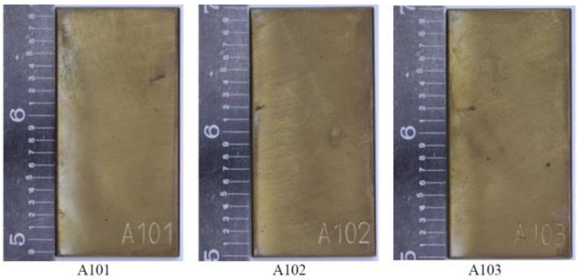

Figure 19. Coupons of a copper alloy

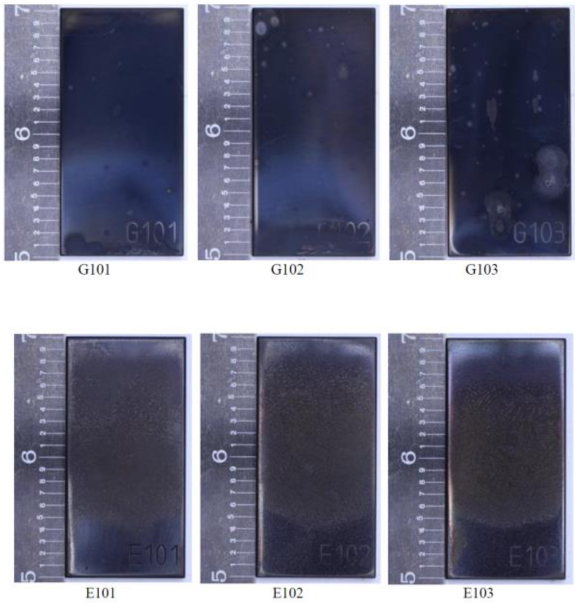

Figure 20. Coupons of an iron and a steel alloy

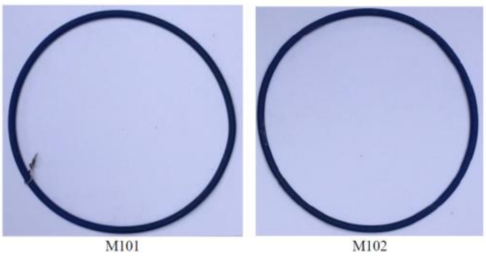

Figure 21. Rubber material

To bring these results to a turbocharger level specifically Accelleron turbochargers, the use of ammonia as a fuel under currently anticipated operating conditions poses a low risk. For metals, the observed corrosion rate is very low. For the rubber materials compared to the metals, these are not directly exposed to the gas flows, but only to gas entering via the clearances between the casing parts. The situation for example gaskets installed in the turbocharger is therefore less critical than at the direct exposure during the tests. Depending on the actual exposure in the turbocharger, the material specification may need to be upgraded to a suitable material.

9 CONCLUSIONS

Net zero shipping will be built on efficiency to 2030, and carbon-neutral fuels to 2050 with many considerations for ship owners and operators. These stakeholders can refer to Accelleron's latest developments to address efficiency needs for their 2-stroke engines and across a larger engine load range in turbocharger cut-out for both new vessels and the existing fleet.

The new ACCX300-L turbochargers come with the added flexibility of an exchangeable cartridge. This increased serviceability addresses the varying maintenance needs and ensures optimal usage of components that will come from turbocharger cut-out systems, dual-fuel engine operation and alternative fuels, identified via digital monitoring services such as Turbo Insights.

Exposure of selected turbocharger materials to an ammonia rich environment in a laboratory investigation provides a better understanding of what to expect as the industry continues with the introduction of ammonia as fuel. The results were aligned with the findings from a first theoretical investigation of material compatibility and therefore under currently anticipated turbocharger operating conditions, the use of ammonia as a fuel poses low risk for Accelleron turbochargers including the ACCX300-L series.

10 DEFINITIONS, ACRONYMS, ABBREVIATIONS

2 (subscript): impeller outlet

CFD: Computational Fluid Dynamics

D_c: Compressor diameter

Dp: Pressure rise coefficient

E (subscript): stage inlet

FE: Finite Element

Δp: pressure difference

ρ: density

PLC: Programmable Logic Controller

SFOC: Specific Fuel Oil Consumption

u: circumferential speed

V_{298}: Volumetric flow rate at 298K

11 ACKNOWLEDGMENTS

The authors would like to thank all colleagues at Accelleron who contributed to this paper at short notice. Either directly to the content or who's efforts could be utilized from the ACCX300-L and/or FiTS2 development. Much appreciation is also extended to the colleagues who took the time to review this paper and offer their feedback.

12 REFERENCES AND BIBLIOGRAPHY

[1] DNV 2024, Energy Transition Outlook 2024 Maritime Forecast to 2050, A deep dive into shipping's decarbonization journey, https://www.dnv.com/maritime/publications/maritime-forecast/

[2] MEPC 80/INF.10 April 3, 2023, Reduction of GHG Emissions From Ships, Report on the study on the readiness and availability of low- and zero-carbon ship technology and marine fuels, https://wwwcdn.imo.org/localresources/en/MediaCentre/WhatsNew/Documents/MEPC80.INF10.pdf

[3] UCL Energy Institute, Getting to Zero Coalition and UN Climate Change High Level Champions, Climate action in shipping, Progress towards Shipping's 2030 Breakthrough, 2024 edition, https://climatechampions.unfccc.int/wp-content/uploads/2023/11/GTZ_ClimateActionInShipping2023-17112023.pdf

[4] Mutter, A., Behrendt, D., Domenig, F., Ma, S., Ruch, D., Senn, S., 2023. Next generation axial turbocharger fit for a carbon-neutral world. *30th CIMAC World Congress*, Busan, South Korea

[5] Maersk Mc-Kinney Moller Center, Transatlantic Testing Ground: Assessing impacts of EU and US policies on accelerated deployment of alternative maritime fuels – January 2024 https://www.zerocarbonshipping.com/publications/assessing-impacts-of-eu-and-us-policies-on-accelerated-deployment-of-alternative-maritime-fuels/

[6] Galloway, L., Spence, S., Kim, S.I., Rusch, D., Vogel, K. and Hunziker, R., 2017. An Investigation of the Stability Enhancement of a Centrifugal Compressor Stage Using Porous Throat Diffuser, *Journal of Turbomachinery*, 140(1), 011008

[7] Hunziker, R., Gyarmathy, G., 1993. The operational stability of a centrifugal compressor and its dependence on the characteristics of the subcomponents. *ASME* Paper No. 93-GT-284

[8] Bouman E.A. et al., 2017, State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review, *Transportation Research* Part D 52 (2017) 408-421. https://www.sciencedirect.com/science/article/pii/S1361920916307015

[9] Ryser, R. 2020. The value of turbocharging for combustion and performance in the application of alternative fuels on large engines, *6th Rostock Large Engine Symposium*, FVTR GmbH, Rostock, Germany, pp. 237-254.

[10] Ryser, R. 2022. Adaptation of turbocharging in interaction with the engine tuning to meet thermodynamic requirements of alternative fuels on large engines, *26th Supercharging Conference,* Dresden, Germany

[11] Ryser, R. et al. 2023. Turbocharging of large engines in decarbonization scenarios: impact for the most likely fuels, Paper 080, *30th CIMAC World Congress*, Busan, South Korea