DESIGN OF AN AIRWORTHY TURBOSHAFT ENGINE QUICK-START SYSTEM WITH COMPACT PRESSURIZED AIR SUPPLY FOR ROTORCRAFT APPLICATION

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Helicopters heavier than light class have two or more turboshaft engines installed, for safety reasons. During helicopter flight missions the maximum installed power is rarely needed. Thus, the engines are mainly running at part load. However, turboshaft engines have the lowest specific fuel consumption (SFC) at high engine loads. This means that the fuel efficiency is poor when the engines are operating at part load conditions. The operational strategy of an intended controlled shutdown of one engine during helicopter flight can be a solution to improve fuel economy. Accordingly, the load of the remaining running engine is increasing and thus, the SFC is shifted to better values and fuel can be saved. But this intended single engine operation (ISEO) strategy is limited to certain areas of the helicopter flight envelope. One constraint is the flight altitude. If the running engine fails during ISEO mode, sufficient altitude margin for autorotation is required. To reduce this margin, the before controlled shutdown engine has to be quick-start capable since regular engine starts last too long until sufficient power can be provided by the engine.
A quick-start system (QSS) for turboshaft engines was designed at the Institute for Flight Turbomachinery and Propulsion. This system utilizes pressurized air for gas generator accelerating during engine start-up. At its first development stage for proof-of-concept the system operates with 13 bar(a) air pressure. However, this air is provided by the testbed building. This QSS is currently modified to operate at pressures up to 300 bar(a). Thereby, the QSS gets independent from the shop air and lightweight pressurized air bottles can be used as air reservoir. This paper deals with the preliminary design of a QSS which is lightweight, airworthy, reliable and capable of being integrated into a helicopter fuselage. For this, the already functional QSS with shop air is analyzed and general system parameters are defined for further system design. Numerical simulations of the system's functionality are performed leading to a basic preliminary design. The next design phase comprises a CAD model and fuselage integration aspects. Based on this preliminary design, a rough weight estimation of the QSS is done. After that, a design review is performed. All steps consider aspects for realization of this lightweight QSS on the institute's engine testbed for experimental investigations later one.

Abbreviations

AIS	Air Impingement System
ASS	Air Supply System
ESPSS	European Space Propulsion System Simulation
GG	Gas Generator
ISEO	Intended Single Engine Operation
QSS	Quick-Start System
SFC	Specific Fuel Consumption

Symbols

$\dot{m}$	Mass flow, [kg/s]
p	Pressure, [bar, Pa]
v	Velocity,[m/s]
t	Time, [s]
A^*	Nozzle throat cross section area, [m²]
F	Force, [N]
I	Jet momentum, [N/s]
R	Gas constant, [J/(kg K)]
T	Temperature, [K]
κ	Isentropic coeffcient, [-]

Indices

air	Air parameter
$exit$	Nozzle exit
i	Sum count
n	Nozzle count
noz	Nozzle related
t	Total Value

1. INTRODUCTION

Reduction of carbon emissions and lowering the noise level based on governmental regulations are future challenges in rotorcraft and propulsion design [1]. Due to high fuel prices, aircraft operators claimed the development of more efficient engines with significant lower fuel consumption a few years ago [2]. Additional savings can be achieved by lowering other direct operational costs as well as maintenance costs. Currently, some objectives can be partially achieved by evolution of already established technologies. One is a modified operational usage strategy of the helicopter's installed turboshaft engines. Current powertrain designs of helicopters heavier than light class comprise two or more engines. This is mainly driven by safety reasons. In case of an engine failure the remaining running engine has to provide sufficient power to maintain flight or to enable a safe emergency landing. Hence, the installed maximum power exceeds by far the usual required power during flight missions. But turboshaft engines have the lowest specific fuel consumption (SFC) at high engine loads [3]. This means, the engines are operating most of the mission time at poor SFC values, causing high fuel consumption. To resolve this predicament, an operational engine usage strategy can be an intended shutdown of one engine during the flight mission at appropriate helicopter flight states. The shut off engine does not consume any fuel and the remaining running engine is higher loaded causing better SFC values. This results in significant fuel savings depending on the flight mission and can be used either to reduce mission-specific fuel consumption or to extend flight mission time [4]. But, due to maximum transmission power or available engine power, neither low or high speed flights nor steep climb flights are possible at ISEO mode. Besides simulations, this operational strategy of intended single engine operation (ISEO) was intended to be investigated by Airbus Helicopters within the Bluecopter research program [5]. However, this does not happen so far.

During ISEO flights, the helicopter's behavior is like a single engine powered one, which means in case of a fatal engine failure there is no shaft power available anymore to maintain flight. A possible solution to mitigate this emergency situation is a re-start of the engine which was shut off before due to switching in ISEO mode. However, a regular engine start for turboshaft engines of the 500 to 1000 kW class lasts about 25 to 30 s just from off-state to idle. Until the engine can provide enough shaft power, further 4 to 8 s are elapsing. If usual autorotation sink rates of 8 to 15 m/s are applied, the helicopter has lost in worst case approximately 720 m of altitude until sufficient shaft power is available again. A solution to ease this situation is a reduction of the turboshaft engine's start-up time. This can be realized by a technical device providing further acceleration torque for the gas generator (GG). A general overview of gas turbine start devices is listed by Pascoe [6]. Based on the requirement of high GG acceleration torque, Hull and Santo made an evaluation of suitable starting devices [7]. One solution is, using a hydraulic motor which requires a hydraulics system at an appropriate pressure level. The results of the experiments were promising but the prerequisite of a working hydraulic system for proper operation may not apply for a helicopter during total engine power loss. Another possibility for high cranking energy supply is Hydrazine impingement or cartridge impingement. This means, directing a high velocity hot gas stream onto the turbine blades [7]. However, the hydrazine solution has drawbacks regarding cots, complexity and health hazards. The cartridge impingement requires too much installation space and has to be replaced after each use [7]. Thus, both propellants variants seem not applicable for practicable engine quick-start. Rodgers [8] picks up the basic idea of impingement nozzles but utilizes high-pressure air or hot-gas as propellant. In addition, an impingement at the compressor section was also investigated. For turbine impingement, hot air of approximately 533 K was used and the GG was just accelerated to 4770 rpm. Since the turbine used for impingement is of radial design, the turbine entry pressure raised with continuing turbine acceleration due to inherent centrifugal static pressure rise. The impingement nozzle outlet is located at turbine entry which means the downstream back pressure of the nozzles is also increasing, causing less nozzle expansion efficiency [8]. Then, proper long term storage of pressurized air at 533 K may be a challenge which cannot be satisfactorily resolved. Thus, impingement of pressurized gas of ambient temperature seems more feasible. Rodgers [8] stated that compressor shroud impingement was the most convenient method for GG acceleration with impingement nozzles. The quick-start tests of a 260 kW gas turbine were conducted with compressed nitrogen at several operating conditions. Final data analysis revealed, that "impingement starting is the most direct method of applying start energy" to the GG [8]. Start times could be reduced by approximately 55%. More details can be found in [8] and [9].

Based on the findings of Rodgers [8], [9], a quick-start system (QSS) comprising impingement nozzles which is directing a gas jet onto the trailing edges of a radial compressor seems to be the best solution for engine quick-starts. But the usage of nitrogen as pressurized gas is not practical since nitrogen cannot be used for any kind of combustion further downstream the gas turbine during impingement. This is a crucial issue, because the compressor showed abnormal operating behavior during Rodger's experimental tests. Depending on the nozzle count and therewith on the resulting mass flow of injected gas, the compressors outlet area suffered kind of throttling which caused compressor surge and backflows. Here, the compressor is not delivering any air mass flow to the combustion chamber and proper fuel burning cannot take place. Thus, using regular compressed air for the nozzles is a more viable solution. For QSS proof-of-concept tests a turboshaft engine has to be chosen. The instrumented and fully functional Allison 250-C20B turboshaft engine of the Institute was a reasonable choice. The engine is of modular design, why a replacement of engine modules is uncomplicated. Its output shaft power is about 300 kW and it has a radial compressor as last compressor stage. This engine design is similar to the engine modified by Rodgers [8] for quick-start tests. Due to this fact, the QSS for the Allison engine is designed with the parameters of Rodgers [9] in mind.

The new radial compressor casing is equipped with impingement de Laval nozzles which are asymmetrical positioned in circumferential direction to avoid harmonic excitation. This air impingement system (AIS) is shown in Figure 1.

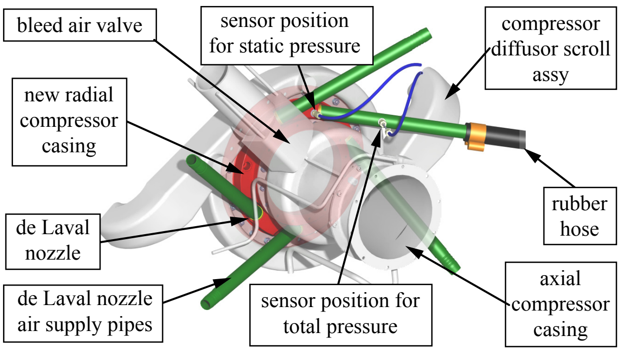

Figure 1: Integration and positioning of the de Laval nozzles.

The nozzle count is mainly restricted by installation space as well as shop air supply pressure. Start performance calculations revealed an optimum and maximum nozzle count of 5. The nozzle angle is defined to provide best impulse propagation to the impeller's trailing edge. The used shop air for nozzle supply is about 13 bar(a) and due to total pressure losses which are caused by valves and the feeding lines, the nozzle working total pressure is 12.3 bar(a). The nozzle's throat diameter is 6.6 mm which means an air mass flow of 0.1 kg/s resulting in 0.5 kg/s overall air mass flow. The Allison 250-C20B engine has a corrected mass flow of about 0.66 kg/s at idle speed (60% of design GG speed). Hence, the QSS provides the engine with almost the air mass flow for idle speed. The design Mach number of the nozzle is 2.3. Operation time of the QSS is 2.2 s and the idle speed of the engine is reached 2.4 s after off-state. During this acceleration phase the starter motor is operating, too. After 0.85 s from off-state, ignition of the injected fuel takes place and the GG turbine provides further power for GG acceleration. Finally, the start-up time to idle can be reduced by over 90% from 26 s to the already mentioned 2.4 s.

This can be observed in Figure 2. But reaching idle speed is not sufficient during autorotation. The helicopter requires shaft power to leave this flight state. A first conservative test with a preset of 100 Nm brake torque is done to investigate power output after quick-start. As Figure 2 shows, the equivalent 60 kW power output (= 20% of max. continuous shaft power) is available within approximately 8 s from off-state. Further details on design and testing of the Allison QSS supplied with shop air can be found in Hönle [10], [11].

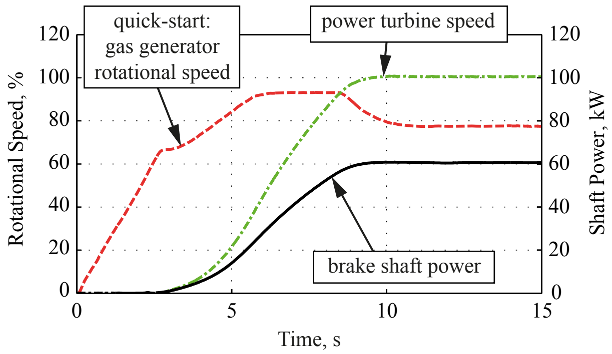

Figure 2: Quick-start rotational speed of gas generator and power turbine as well as delivered shaft power.

The results show the successful application of the QSS on a 300 kW turboshaft engine regarding proof of concept and demonstrating system's functionality. At this development stage the QSS is supplied by shop air and thus, not capable of being integrated into a helicopter. Hence, the next step is designing an air supply system which provides sufficient pressurized air for the nozzles. In addition, it should have compact dimensions for helicopter airframe integration and this should be done without any extensive structural airframe modifications. Due to cost and manufacturing time issues, the AIS, which comprises the modified casing, nozzle design and the supply pipes to the nozzles, should not be modified. Thus, the changeable design parameters apply mainly on the air supply system (ASS).

2. DESIGN PARAMETERS OF THE AIR SUPPLY SYSTEM

The proof-of-concept QSS has five de Laval nozzles to achieve reasonable additional GG acceleration torque. The geometry of the radial compressor rotor is fixed and thus, a variation of momentum force of the de Laval nozzle's air jet can only change the acceleration torque. This jet momentum I_{air} and its resulting thrust force F_{noz} are defined in Equation (1).

$$\sum_{i=1}^{n} \frac{dI_{air,i}}{dt} = \sum_{i=1}^{n} F_{noz,i} = \sum_{i=1}^{n} \left(\dot{m} \cdot v_{noz,exit}\right)_i \quad (1)$$

On the one hand a momentum change can be realized by either changing the mass flow $\dot{m}$ through the nozzles or vary the air velocity $v_{noz,exit}$ at the nozzle exit. On the other hand the nozzle count n has influence on the momentum sum, too. Since weight saving is an important issue for helicopters, a reduction of the nozzle count is desirable to cut down the QSS part amount. This comes along with increasing the air velocity $v_{noz,exit}$ and/or the mass flow $\dot{m}$ to keep the momentum sum and therewith acceleration torque. In general, the QSS is working at choking conditions. This means, the air mass flow $\dot{m}$ is restricted by the throat diameter of the nozzle. The analytical approach to determine the mass flow rate $\dot{m}$ at this chocking condition is described with Equation (2).

$$\dot{m} = A^* \cdot \sqrt{\frac{\kappa \cdot (1+\kappa)}{2 \cdot R \cdot T_t}} \cdot p_t \cdot \left(\frac{1+\kappa}{2}\right)^{\frac{-\kappa}{\kappa-1}} \quad (2)$$

The nozzle throat cross section area A^* is fixed due to the nozzles fixed geometry. Both gas constant R and isentropic coefficient κ are described by the fluid type and are given, since normal air is used. Furthermore, if choking condition is valid, the mass flow $\dot{m}$ does not depend on the ambient pressure at the nozzle outlet. But with a variation in total pressure p_t at nozzle inlet, the mass flow can be changed. By means of nozzle count reduction to three, the nozzle inlet total pressure has to increase. This cannot be realized with the shop air supply. Thus, air pressure tanks with greater pressure than 13 bar(a) have to be used. The final exact and feasible pressure level has to be determined for proper QSS operation. Furthermore, the total temperature of the used gaseous fluid T_t is also a parameter in Equation (2). It appears in the denominator, which means a higher total temperature causes lower mass flow rates. Lowering the gas temperature will increase the mass flow. As stated before, air pressure tanks are used as pressurized air supply. An expansion of the stored high pressure air leads to cooling-down of the expanded air. But the expanded air flows through several pipes, devices and hoses which are at ambient temperature. As a result, the cooling effect would get less distinctive. But this effect must be quantified by experiments since realistic simulations of heat conduction and heat transfer effects would require sophisticated heat transport models. The probable findings would be disproportional to the expected necessary effort of model creation as well as proper boundary condition definition. A lower air temperature of about 30 K would increase the mass flow in best case by only 6%. Summing up, keeping the same acceleration torque with fewer nozzles requires an increase in nozzle entry total pressure. This pressure variation was investigated by

Rodgers [9] as well. He did tests with one, two, three and five active nozzles and varies the air pressure. The results are shown in Figure 3. The tests are declared as cold-crank test. It means, only the nozzles are active and thus none turbine operation or starter generator support.

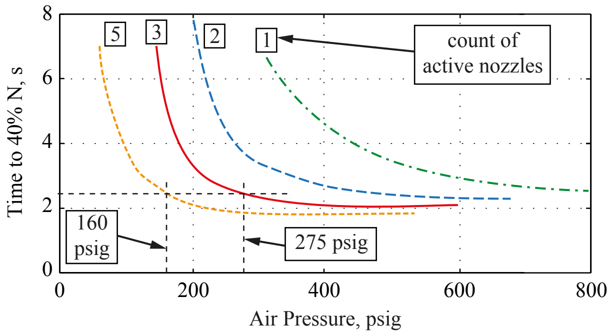

Figure 3: Start-up time to 40% gas generator speed depending on nozzle count and nozzle pressure [9]

With five active nozzles and the design nozzle pressure of about 160 psig (~11 bar(a)) the start-up time to 40% rotational speed of the gas generator is about 2.45 s. The same start-up time can be achieved using only three nozzles but with an increased nozzle pressure up to 275 psig (~19 bar(a)) [9]. The results lead to the following conclusions: A higher pressure than the design pressure at the design nozzle count configuration does not cause signification lower start-up times. Moreover it causes a negative compressor flow, which means a backflow inside the compressor. This phenomenon was also observed at the Allison engine during quick-start [12]. However, reducing the active nozzles count means increasing the nozzle pressure level to keep the same start-up time. A further increase of pressure does not lower the start-up time. But if the nozzle count is further reduced, the pressure level has to be increased to keep almost the start-up time. But the engine has to cope with the greater static flow pressure after the nozzles. Thus, increasing nozzle pressure for better start-up performance is only reasonable up to a certain pressure level.

Besides nozzle count and nozzle pressure, the overall piping of the system is an important design parameter. The wetted surface of the piping components has to be minimized to avoid excessive total pressure loss between the pressurized air storage device and the nozzles. The length of these piping and hoses components has to be kept as short as possible because the minimum required diameter of pipes and hoses are often determined by the defined maximum overall mass flow of 0.5 kg/s. Then, flow path bending as well as excessive flow path diameter changes should be avoided since this causes pressure losses. One criterion for valves is here a low pressure drop over the device. Another parameter of total pressure losses is the flow velocity inside the pipes, flexible hoses and devices. Here, a trade-off between pressure loss and component weight has to be found. The flow velocity and therewith the pressure losses can be reduced by increasing the flow path diameter but this means also further component weight. For weight improvement, small diameters would be the best solution but this leads otherwise to higher pressure losses. And as stated before, a minimum diameter exists due to the required overall mass flow.

The Allison QSS with shop air supply has a pneumatic piston operated 2/2-way valve for releasing the pressurized air. Due to lack of detailed valve documentation, the opening and closing times are not exactly known. Similar valves have opening and closing times of about 360 ms. Since this time span is quite long in comparison to the overall QSS operation time of approximately 2.2 s, another important system parameter of the airworthy QSS is the valve opening and closing time. The acceleration capability can be further enhanced with shorter time spans.

Based on these findings, a preliminary design can start to select general system components. After that, first simulations are performed to evaluate the preliminary design.

3. PRELIMINARY QSS DESIGN

The preliminary design should deliver important data like the size of the pressurized air tanks, length and diameter of pipes and hoses as well as size of adapters and fittings. In addition, appropriate valves and pressure regulators have to be chosen. Since the QSS should be of airworthy design, the used components have to be aerospace certified. Since this paper shall only give a possible solution for an airworthy QSS, the design is based on public data of such components. Upcoming functional tests of the QSS take place at an engine test-bed. Here, weight saving is not essential as well as the usage of aerospace certified components is not required. Instead, mainly components of the hydraulic sector and industrial sector are used. But these components are selected with respect to the capability of its aerospace counter piece.

The final design comprises three nozzles. The uneven number is selected to avoid mechanical vibrations due to excitations. Then, the five available nozzle positions allow a nearly equally spaced distribution of three nozzles along the circumference. The required increase of nozzle entry total pressure is realizable, too. The experiments of Rodgers [9] with an engine of similar power class showed just an increase by 8 bar(a) total pressure due to nozzle reduction from five to three to keep same acceleration times. This means for the Allison QSS to increase the nozzle thrust from 50 N to 83.5 N. Simulations are performed with the simulation program ESPSS to get the correspondent pressure. The common usage of ESPSS is the 1D simulation of space propulsion systems. Since such systems comprise de Laval nozzles and high pressure fluids, the software program is appropriate for this calculation. In general, ESPSS is based on the simulation framework provided by the generic system simulation tool EcosimPro. It is capable of modelling dynamic systems which are represented by differential-algebraic equations as well as ordinary differential equations and discrete events. Additional information about the software is described by Isselhorst et al. [13], Pérez-Vara et al. [14] and Moral et al. [15]. In-house model validation was done with the shop-air QSS as well as with tests prior to the new nozzle entry pressure determination. These results are described in publication [16]. The simulations showed a requirement of 18.3 bar(a) total pressure at nozzle entry to achieve 83.5 N nozzle thrust. Tests at the nozzle test-rig were conducted with this pressure setting. A thrust of 80.4 N was measured which means a deviation of 3.9%. However, due to several assumptions as well as measurement inaccuracies this result is accepted as accurate enough for ongoing QSS preliminary design. Which means, the ASS has to provide around 20 bar(a) nozzle entry total pressure. In the following the ASS is sketched which can provide this pressure requirement.

Each nozzle has its own supply pipe, which can be seen in Figure 1. The inner diameter of the stainless steel pipes is 14 mm and the outer diameter is 18 mm. Thus, the hose connected from any kind of pressure source to the pipes should be of same inner diameter. Aircraft suppliers offer lightweight medium pressure hoses with a relative weight of 0.43 kg/m. These have an inner diameter of approximately 17.5 mm and an operating pressure level of about 70 bar(a). Appropriate fittings have a weight of 0.18 kg each.

A three-way air distribution manifold is required to feed each nozzle from one supply line. This part is custom made and after weight optimization it weighs less than 1.0 kg. The manifold is directly connected to a valve, which releases the pressurized air. This short connection keeps the volume inside the nozzles, hoses and manifold low, since during regular engine operation the air volume has the same pressure level as at the impeller outlet. The pressure at the nozzle exit location is changing equally to the engine load. This means during highly dynamic engine operation the volume behaves like a pressure reservoir or drain. This may cause unexpected compressor instabilities and has to be further investigated since it depends highly on the engine type. The usage of heck valves directly at the nozzles is rejected due to the high weight of valves appropriate for such mass flows.

A coaxial operating valve for high pressure releasing is selected. The advantage is that with increasing difference pressure between the high and low pressure side the required forces for valve operation are not very high and are not directly depending on the high pressure. Thus, the valve's piston can be moved just with adequate electromagnetic forces. Other advantages are very short opening times below 100 ms, reliability, and little weight relative to the maximum flow rate through the valve. The exit of the valve encounters the compressor pressure and the valve entry is loaded with a pressure level equaling the nozzle entry total pressure plus the valve's pressure drop value during operation. Typical weight of a coax valve meeting the QSS requirements is about 5.5 kg. However, this is a variant which is not weight optimized yet. For safety reasons the valve has to be normally closed. If there is a loss of electricity the valve shall not operate in an unexpected manner.

With a pressure regulator, the high pressure level of the pressurized air storage device can be reduced to the required value of the nozzles and design volume can be saved by highly compressed air. The pressure regulator is mounted direct to the valve to keep pipe length short and avoid losses. Therewith, highly pressurized pipes can be kept at a minimum. The pressure regulator must handle inlet pressures of about 300 bar(a) and outlet pressures of about 50 to 20 bar(a). Suitable pressure regulators have a weight of 3.8 kg. Such devices are also able to relieve remaining pressurized air within the piping, which is a safety requirement for maintenance and component replacement.

A composite air bottle is a suitable solution for pressurized air storage. Compared to steel bottles, the light weight is an advantage. Typical weight of a 15 l carbon and glass fiber bottle with aluminum liner and 300 bar(a) working pressure is about 9 kg. Such bottles are already certified for aerospace application. Between bottle and pressure regulator is an adapter and a needle valve. The adapter is used for bottle condition monitoring as well as for bottle pressurization. The needle valve is required for safe bottle replacement. For weight saving, only one bottle is used to supply both AIS of the engines with pressurized air. This means, a manifold block with two output lines (1/2) is used between the pressure regulator and the coaxial valves. This is shown in the airworthy QSS scheme in Figure 4.

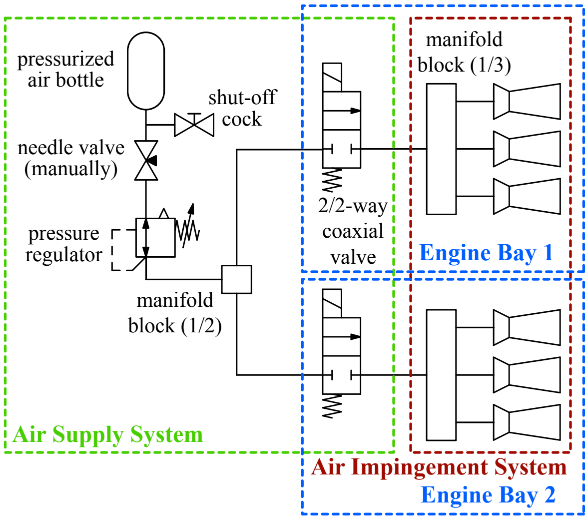

Figure 4: Scheme of the airworthy quick-start system

Additional weight is caused by component mounts and engine modifications for realization of quick-start capability. The latter one depends on the engine type and thus, a common valid figure of weight changes cannot be given. A safety issue to be considered is the number of possible quick-starts. The QSS is first of all an emergency system which has to operate properly. However, a first quick-start may fail due to several reasons. Thus, there has to be the possibility to perform a second quick-start. With ESPSS simulations in advance, the required bottle volume is estimated. A volume of 15 l compressed air of 300 bar(a) is required to maintain two consecutive quick-starts. Some boundary conditions for the simulation are applied, for instance the QSS has to provide the same thrust for 2.2 s operation time for each time of use. This means keeping the adjusted pressure after the pressure regulator at a constant value to ensure constant nozzle entry pressure. Figure 5 shows the observed nozzle mass flow of two consecutive QSS operations.

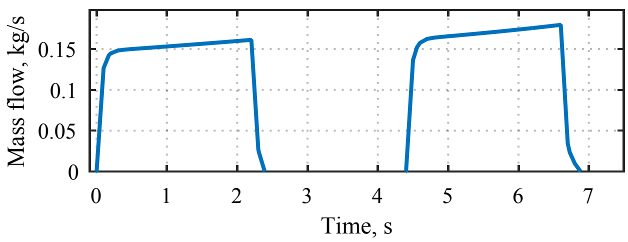

Figure 5: Mass flow of one nozzle of the airwor. QSS preliminary design for two consecutive operations

The mass flow is slightly increasing over operation time. The pressurized air is expanding and due to real gas effects the air temperature of the expanded volume is decreasing. Consequently, the air density is increasing which causes a higher mass flow for the same pressure level. Due to Equation 1, the nozzle thrust is increasing as well. Since none adjustments on the pressure regulator are done for the second QSS operation, the thrust goes up to 90 N. The curve characteristic of the simulation is shown in Figure 6 and it is similar to the mass flow curve.

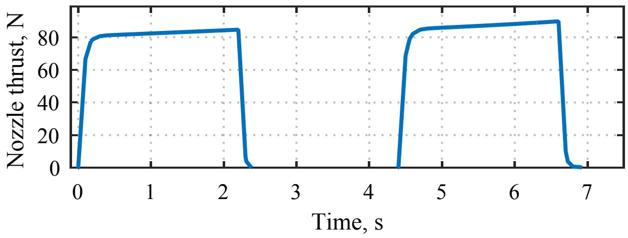

Figure 6: Thrust of one nozzle of the airworthy QSS preliminary design for two consecutive operations

The design thrust of 83.5 N is achieved after 1.6 s from first QSS start. The temperature decrease within the QSS due to air expansion may be a problem which has to be investigated directly at engine starts. The bottle pressure is shown in Figure 7. After the first QSS operation, the pressure has dropped from 300 bar(a) to 178 bar(a). The air temperature inside the bottle dropped also from predefined 293.15 K to approximately 254 K.

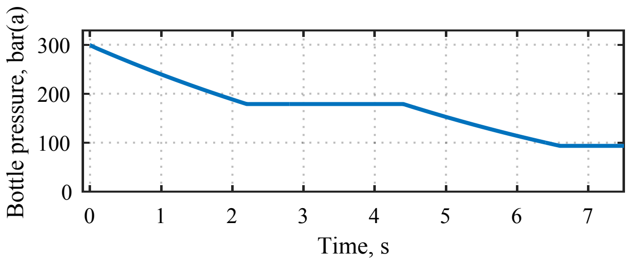

Figure 7: Bottle pressure of the airworthy QSS preliminary design for two consecutive operations

After the second QSS operation the remaining bottle pressure is 93 bar(a) and the air temperature inside the bottle has reached a minimum of 211 K. The static air temperature at nozzle exit is for the second QSS operation only 106 K. As already stated, this may cause combustion instabilities for the first few seconds after engine off-state where the injected QSS air is primarily used for combustion. Then, engine parts may suffer additional thermal stress due to the low temperatures. Preliminary tests of the QSS at the Institutes testbed will be done for further investigation of this temperature problem. The remaining bottle pressure is sufficient to cover not yet considered total pressure losses within the QSS due to additional pipe and hose bending. The ESPSS simulation is already performed with a 90° hose bending between the block manifold (1/3) and the supply pipes. When the airworthy QSS is virtually constructed, corresponding ESPSS simulations have to be performed simultaneously to adjust final QSS parameters. However, QSS performance can be enhanced by keeping pipes and hoses short and by avoiding sharp bending of the flow path. The final flow path will be certain after virtual design of the QSS.

4. FINAL AIRWORTHY QSS DESIGN

Since the QSS is tested with an Allison 250-C20B engine, which is installed at the Airbus Helicopters BO 105 rotorcraft, this final airworthy QSS design is based on system integration into a virtual engine bay model of the BO 105. Main aspects are keeping the required airframe modification as low as possible and to avoid excessive cowling modifications. Another important issue is the positioning of heavy components at the helicopter because rotorcrafts are quite sensitive due to variation of its overall center of gravity. Then, the engine bay is divided with firewalls into several compartments. Due to safety reasons, important QSS components should not be placed at possible fire exposed areas. Only the supply hoses of the AIS are placed in this area. A possible arrangement of the QSS and a detailed render of the ASS are shown in Figure 8.

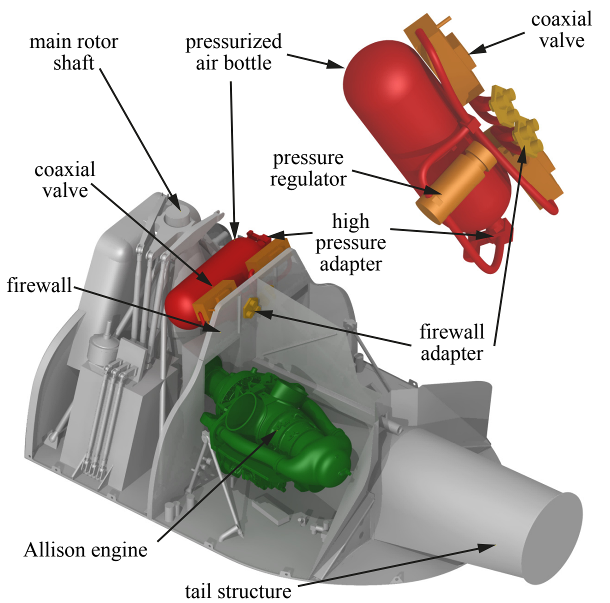

Figure 8: CAD model of a possible QSS arrangement within the BO 105 fuselage

The hoses of the AIS between the firewall adapter and the nozzles are not displayed within the render. But sufficient space is available for proper hose laying. The pressurized air bottle can be attached to the main transmission struts and is located between the front firewall and the main transmission above the engine inlets. The pressure regulator is located below the air bottle and between the air inlets. The coaxial valves are between the front firewall and the air bottle. All these components can be attached to the support structure of the air bottle. The firewall adapters are directly screwed to the front firewall. The QSS nearly fits into the engine bay. The bottom of the bottle and the adapter at the bottleneck are colliding with the engine cowling. This can be solved with a small bulge of the cowling on both fuselage sides.

Despite the system positioning, the airworthy QSS weight is also an important parameter. The stored air has a weight of 4.85 kg. An appropriate composite air bottle for aerospace application with 15 l volume has a weight of 9 kg. An adapter for the bottleneck and needle valve as well as filling valve have in total a weight of 2.85 kg. A pressure regulator for the working pressure range up to

300 bar and required mass flows weighs about 2.8 kg. The used coaxial valves are quite heavy with a weight of 5.5 kg each. However, this type of valve is the best solution for the QSS. Manifolds, fittings and hoses have a typical weight of 4 kg in total. Without any support mounting structure, the ASS and the AIS have an overall weight of 41.4 kg. The system is capable of supplying two engines with pressurized air for two consecutive quick-starts. For mountings and wiring a weight of 5 kg can be assumed. Thus, the final weight of the QSS is 46.4 kg. The control of the QSS should be implemented into the FADEC of the engine if applicable. Both engines FADEC have to cross talk to be able to restart the right engine at engine failure during ISEO. The workload of the pilot should be reduced to a minimum in this critical situation.

5. DESIGN REVIEW AND OUTLOOK

In this paper a possible design of an airworthy and compact QSS for turboshaft engines is presented. Therefore, the current QSS operating with shop-air is investigated to identify changeable parameters to meet the requirements of an airworthy QSS. The AIS cannot be modified and thus, the ASS parameters like nozzle entry total pressure have to be changed. Based on these findings, an ESPSS model of a preliminary design concept is set up to identify the necessary pressure level at nozzle entry. In addition, the volume and pressure of a pressurized air reservoir is also calculated. It is specified having the capability of two consecutive quick-starts. This can be achieved with a 15 l pressure bottle filled with pressurized air of 300 bar(a). Sufficient pressure margin is available with this configuration to cover further total pressure losses of the final QSS design. This final design is placed at the BO 105 engine bay without any heavy structural airframe modifications. However, just the cowling has to be redesigned. From a systems weight point of view, the QSS with 46.6 kg may be still too heavy. With additional more sophisticated analysis, simulations and experimental tests, the system weight can be optimized. This comprises better component positioning, therewith shorter pipes and hoses and more suitable valves and pressure regulators. But this has be the task of a future system manufacturer.

The described system of this paper will be realized and tested at the institute's testbed with the Allison engine. Due to cost reasons, the used parts are mainly from the hydraulic sector but shape and geometries are similar to the components in aerospace applications. Possible problems like the expanded cold air can be investigated and hopefully solved. Malfunctions as well have to be investigated. For example, the QSS is activated anyhow during regular engine operation.

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