Novel In-Situ Aircraft Oxygen Cylinder Refilling Tool

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Abstract

Currently, oxygen cylinders installed in an aircraft require refilling once to three times per production cycle for testing the oxygen system. Refilling a cylinder requires removal from the aircraft, transportation to the fill shop, performing the filling operation, returning to the aircraft, reinstallation, and retesting the oxygen system. Opportunity exist for damaging cylinders and contamination of the oxygen system along with adding a recurring potential for mistakes in the removal and installation of the cylinders and pressurization and depressurization of the system.

A novel tool was developed to eliminate this lengthy and potentially hazardous way of working. Using the newly defined tool, oxygen cylinders no longer need removal from the aircraft. Only the pressure regulator must be removed from the cylinder assembly and the tool and fill cart attached to the cylinder, while remaining in its installed position. This process saves time and money as well as increases safety, both for personnel as well as for equipment.

The tool is an assembly of existing qualified aircraft oxygen system parts and a pressure relief valve connected with copper based tubing. It is designed to minimize the potential fire hazard due to adiabatic compression heating during the filling operation.

Keywords
Oxygen, tool, aircraft, refill, operation

1. Introduction

Removal and installation of oxygen cylinders used for aviation emergency supplemental oxygen has been found to be a burdensome task for aircraft production lines as well as during aircraft servicing between flights. The time considerations are important by themselves due to the leak tight connections that must be disconnected and reconnected between the aircraft oxygen system and the detaching and securing of the cylinders within the aircraft. The sometimes cramped spaces that must be navigated with tools and cylinders by aircraft oxygen technicians when removing or installing the cylinders, also requires careful moving in the aircraft compartments. However, more important is the possibility of damaging the system connections or cylinders during the removal or installation process. There are abundant opportunities to scrap cylinders and equipment that are not designed to be handled often. While the cylinders themselves are not fragile, nicks, and cuts to the composite outer coating is a quality defect that cannot be allowed for a new aircraft. Transportation of the cylinders from the aircraft to an oxygen shop, where the cylinders are refilled and inspected, and back also has a potential for delays due to tracking paperwork and waiting on a time slot in the oxygen shop. Another concern is that dealing with high pressure oxygen is a safety hazard which demands a high level of training and concentration to limit the dangers of an ignition event. The potential for leaks that lead to an oxygen enriched atmosphere is multiplied by the number of times a cylinder is removed and installed. Leak tests must be performed after each installation adding to the time the system is non-operational.

To mitigate the probability and consequence of damage, time delay and adverse safety events, a novel tool was envisioned that allowed the refilling of oxygen cylinders without them having to be removed from the aircraft.

1.1 Objectives

The objectives of this tool development project were:

- Design a tool that safely refills an oxygen cylinder without removing it from the aircraft.
- Eliminate the probability of damaging equipment during the removal, transportation and reinstallation of an aircraft oxygen cylinder.
- Reduce the time needed to replenish an aircraft oxygen cylinder during production or flightline operations.

2. Literature Review

It has long been known that aircraft oxygen filling systems are inherently dangerous, resulting in fires that have destroyed aircraft while being serviced on the ground (NASA 2019). As shown in Figure 1, one such accident that resulted in the total loss of the aircraft, but no reported injuries was a SCAT airlines Boeing 737-300 in Aktau, Kazakhstan on 16 June, 2015 (Kaminski-Morrow 2019).

Figure 1: SCAT Airlines Fire

Image credit: (Kaminski-Morrow, 2019)

Industry guidance on oxygen cylinder filling and fire mitigation has been offered by the American Society of Testing and Materials (ASTM) for the design and safe operation of oxygen systems. ASTM Committee G04, Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres, is the arm of ASTM concerned with writing the guidance in forms of handbooks and international standards. (ASTM 2015).
Further industry guidance for aircraft oxygen systems design and operation has been offered by SAE International. (SAE 2012). Very specific design guidance was issued by SAE on the filling valve for oxygen systems (SAE 2012); an Aircraft Oxygen Replenishment Coupling for Civil Transport Aircraft (design standard) (SAE 2002); and Transfilling and Maintenance of Oxygen Cylinders (SAE 2020).

Despite the guidance issued by various government and industry authorities on the subject of oxygen systems design and operation, there have been no devices found that act as a safety filling tool to go between the oxygen service cart and the aircraft oxygen cylinder. Several patents were reviewed to see if a device patent was granted or applied for in

the U.S. Patent Office. One was a patent application to provide oxygen for EMS services, fire departments, hospitals etc. (Fry 2006). Another patent focused on a portable oxygen concentrator system that was user transportable (Hill et al 2003). A third patent described a therapeutic oxygen supply apparatus including compressor and various sensors (Burkot et al 2020). There were no patents or patent applications found describing the tool developed and the research described in this paper.

Literature review provided good design and operation input for the development of the refilling tool, but no evidence that such a tool had ever been patented.

3. Methods

The development of the tool started with the allocation of functions to logical layer blocks and then the use of as much Commercial-off-the-shelf (COTS) aircraft qualified components as possible. As shown in Figure 2, a pre-existing part was available that already included a filter and a calibrated orifice to ensure clean oxygen would flow from the filling cart apparatus through the orifice into the aircraft cylinder. Compress Gas Association (CGA) 540 couplings are integrated into the aircraft oxygen cylinders. A manual pressure relief valve and exit filter allows for the release of pressurized oxygen from the tool and lines between the oxygen service cart and the input CGA port on the cylinder once the hand valve on the cylinder is closed. Once the filling tool is depressurized, it may be removed from the cylinder CGA fitting and the regulator in the aircraft oxygen system may be re-attached.

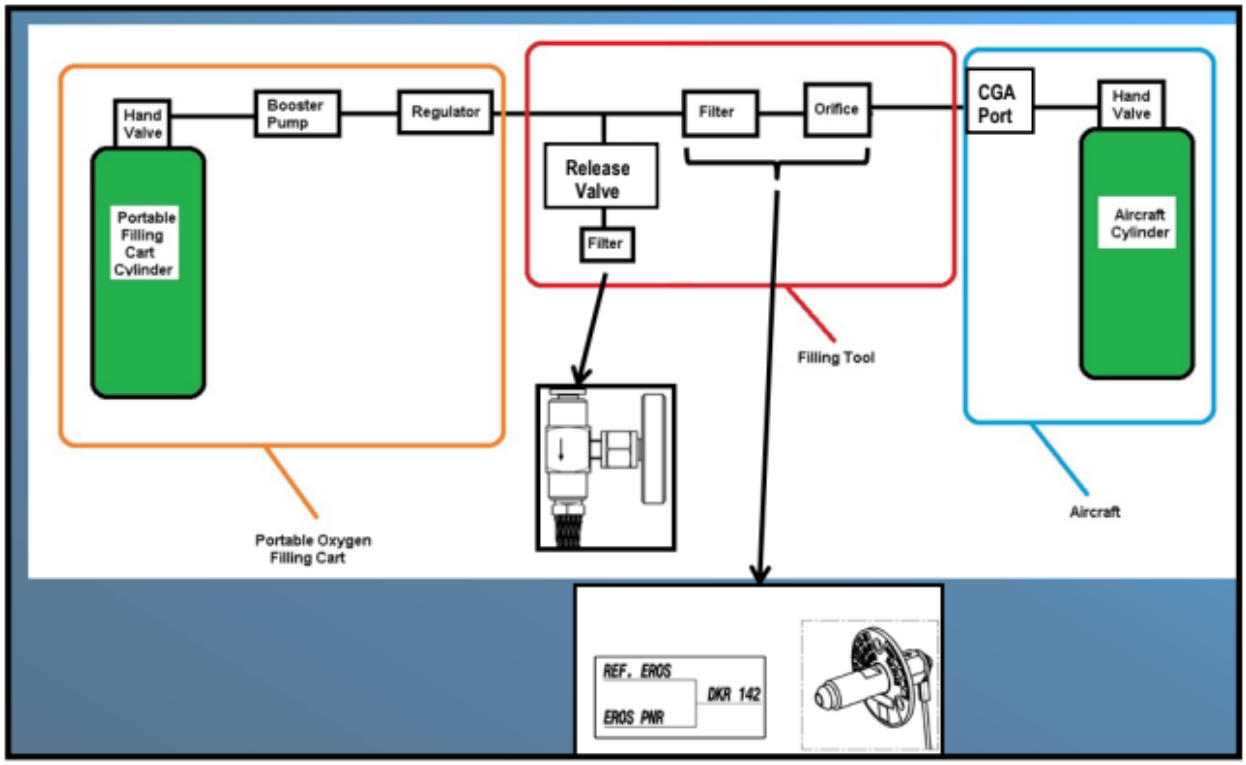

Figure 2: Schematic of Filling Operation

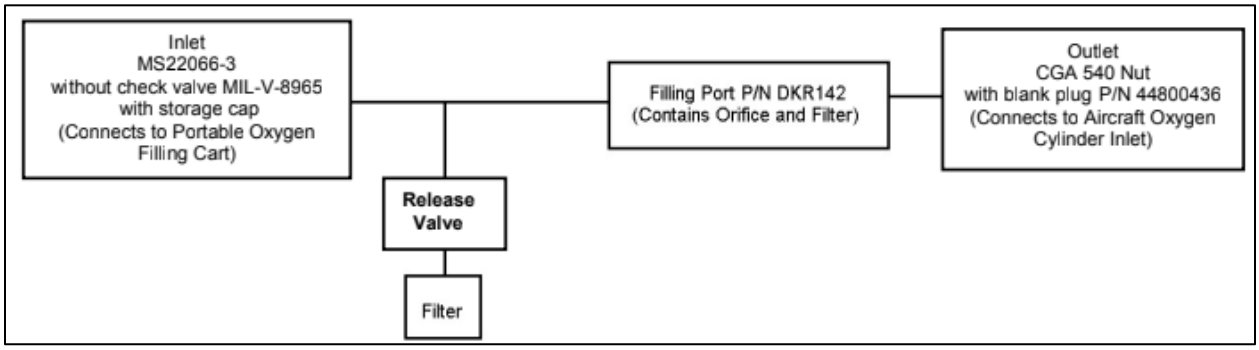

Figure 3: Part Numbers Associated with Schematic of Tool

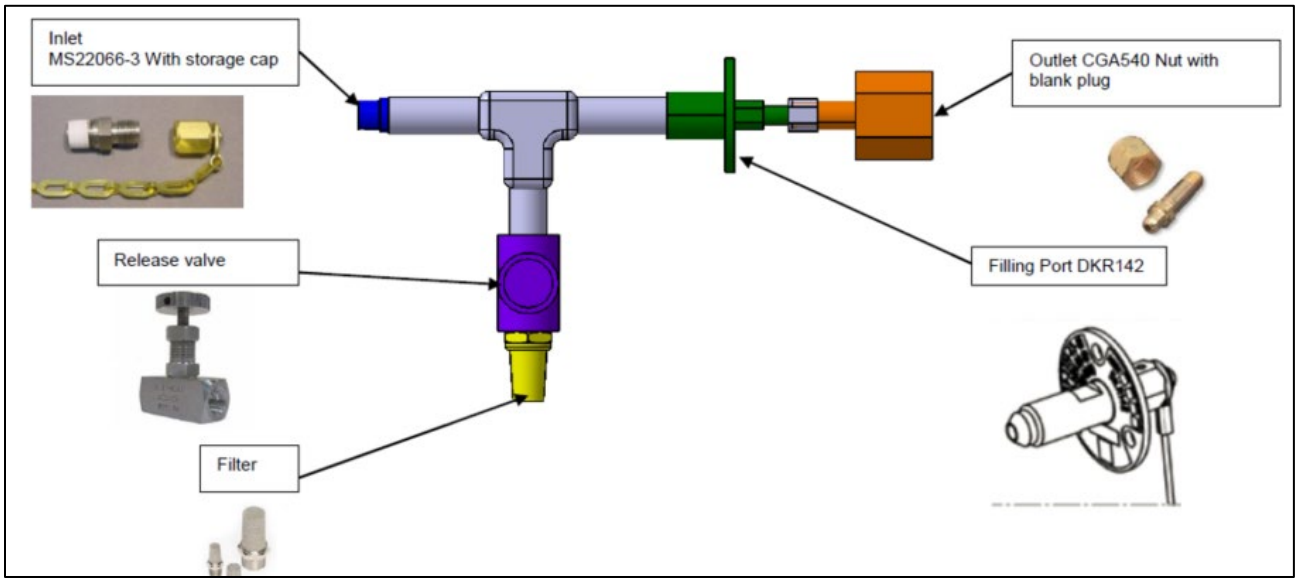

Figure 4: Model of Filling Tool

The new oxygen filling tool has the Airbus tool designation of D352-70541-000W9999-07.

4. Validation

Test procedures were developed to prove the pressure holding ability of the tool and functionality. Pressure testing was performed at proof pressure using clean nitrogen and carried out in accordance with the procedure detailed in paragraph 4.1. Functional testing of the tool was carried out in accordance with the procedures in 4.2.

4.1 Proof Pressure Test procedure for Tool Part Number (P/N) D352-70541-000W9999-07

(1) Cap the tool outlet with pressure sealing cap Compressed Gas Association (CGA) 540 plug, P/N 44800436 (MFG 92003) or P/N 2003019 (MFG 0T652) or equivalent. Connect the filling tool inlet to a nitrogen gas supply (acc. A-A-59503, Type I, Class I, Grade B).

a. Max. allowed pressure of the test nitrogen supply: 213 barg (3090 psig)

Note: Gas pressure dimensions are Psig (pound force per square inch, gauge) and Barg (Bar gauge.)

b. Proof pressure of the Ground Support Equipment (GSE): 210 barg (3040 psig).

(2) Apply Sherlock -5 Type CG, leak detection fluid to completely cover the tool.

(3) Apply slowly and carefully the pressure until maximum operating pressure, 140 barg (2031psig) is reached.

(4) Apply again leak detection fluid to the tool.
(5) Maintain maximum operating pressure, 140 barg (2031psig) for 2 minutes minimum. Verify no bubbles
(6) Increase the pressure slowly and carefully until proof pressure,210 barg (3046 psig) is reached.
(7) Apply again leak detection fluid to the tool connections
(8) Maintain the proof pressure, 210 barg (3046 psig) for 2 minutes minimum. Verify no bubbles.
(9) Close the test gas supply and depressurize the tool,
(10) Disconnect the tool from the testing equipment.
(11) Complete Table 1 to record observations from step (5) and step (8). No bubbles should be observed.

Table 1: Proof Pressure Test Data

Test Pressure	Bubbles During Test (Yes/No)
140 barg	**No**
210 barg	**No**

4.2 Functional Test procedure for D352-70541-000W9999-07

(1) The oxygen service trailer positioned as close as possible to the crew oxygen cylinder.
(2) Observe the safety distances and put the warning notices in position.
(3) Avoid direct sunlight to the oxygen cylinders of the oxygen service trailer.
(4) Ground the oxygen service trailer with a bonding line to the (grounded) aircraft.
(5) No switching operations are allowed.
(6) Stop ground service operations.
(7) Measure the outside air temperature (OAT) and the cockpit temperature with a thermometer (T°C = 0,5 x [OAT °C + Cockpit °C]). Read the maximum filling pressure at this temperature at the Temperature/Pressure Placard Diagram, Figure 5.
(8) Check that the hydrostatic-test date of the installed oxygen cylinder is not expired.
(9) Close the valve of the oxygen cylinder.
(10) Record the pressure on the gauge of the oxygen cylinder. You can use a ruler for linear interpolation to read the gauge.
(11) Open crew supply solenoid valve (crew supply p/b OFF legend off)
(12) Release pressure via Captain and First Officer masks: At the same time press the PRESS TO TEST AND RESET control lever and the PRESS TO TEST/EMERGENCY knob on the mask regulator.
(13) Open electrical circuit breakers
(14) Disconnect the reducer from the aircraft oxygen cylinder.
(15) Put a cap and bag on the reducer connection.
(16) Before connecting the tool, D352-70541-000W9999-07, to the aircraft cylinder, the filling hose shall be blown down for a short moment to ensure contamination is not present within the first few inches of the line.
(17) Connect filling tool, D352-70541-000W9999-07, to the aircraft oxygen cylinder and torque the connection to 70 - 80Nm.
(18) Warning: Do not open the oxygen cylinder at this step. .
(19) Pressurize the oxygen filling line to 100 psi higher than the aircraft oxygen cylinder pressure.
(20) Fully open the aircraft oxygen cylinder and start the filling process.
(21) Observe the aircraft oxygen cylinder pressure gauge and adjust the fill line pressure to achieve the desired cylinder pressure. (Do not exceed fill rate 300 psi/min).
(22) When the desired cylinder pressure is achieved, fully close the aircraft oxygen cylinder hand valve.
Note: After some time, the filled oxygen cylinder will be cooled down close to ambient temperature. The cylinder pressure observed on the cylinder gauge previously
will be decreased by about 10 %.The filling pressure values in the Temperature/Pressure Placard Diagram (Figure 5) contains approximately 10 % “extra” pressure to account for a pressure drop due to cylinder cooling. To estimate the cylinder pressure after cool down, 10% must be subtracted from the pressure values on the Temperature/Pressure Placard Diagram.
(23) Close the shut off valve of the oxygen service trailer.

(24) Release the pressure from the filling hose by opening of the bleed valve of the tool, D352-70541-000W9999-07.
(25) Disconnect the tool, D352-70541-000W9999-07, from the aircraft oxygen cylinder.
(26) Connect the reducer to the aircraft oxygen cylinder and perform system leak check.
(27) Remove the warning notices and inform other workers about finishing of the refilling operation.
(28) Remove the tool, D352-70541-000W9999-07, from the oxygen service trailer.
(29) Protect the open connections with appropriate caps.
(30) Store the tool, D352-70541-000W9999-07, in the appropriate case made for the tool.
(31) Remove the grounding cable and store it.
(32) Otherwise obey the instructions of the aircraft and oxygen service trailer suppliers by operating of valves and filling equipment.

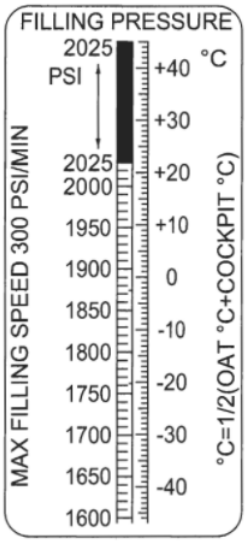

Figure 5: Oxygen Filling Placard

Opportunity to further use the tool in the production environment has followed the above functional test procedures or similar procedures with no adverse reports.

4.3 Estimated Benefits

The estimated time savings per refill was calculated to be 2.58 hrs. with approximately 1600 cylinders being refilled each year. The time savings per year would be approximately 4,128 hours. Actual tact time data and approximate cost savings for labor and reduction of scrap is not available for this paper.

5. Conclusion

The oxygen filling tool was found to be a new development in the realm of refilling oxygen cylinders aboard aircraft. It provides a safe and efficient means to avoid damaging cylinders due to removal and reinstallation after servicing in an oxygen shop. The ability to safely refill the oxygen cylinders while still installed in the aircraft saves time and prevents mistakes that may result in equipment scrapping and replacement or an oxygen fire. Testing and subsequent usage in the production environment provided proof that the tool works as designed and provides the time savings and reduced opportunity for equipment damage hypothesized.

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Biography

Allan Lang is a Principal Systems Engineer at Airbus Americas Engineering, Inc. During the development of the tool, Mr. Lang was a member of the Oxygen System Design Office, in the Mobile, Alabama Engineering Facility. He is currently attending the University of South Alabama in pursuit of a PhD in Systems Engineering and has a BEng in Materials Engineering Auburn University. Mr. Lang is a member of ASTM Committee G04 on Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres and is the Airbus focal for Oxygen Hazards and Fire Risks Analysis (OHFRA).

Robert Thompson is the Head of MAP Engineering –Systems at the Final Assembly Line (FAL) in Mobile, Alabama. MAP is a French acronym for "Mise Au Point", which means the MAP engineer acts on behalf of the engineering design office on the manufacturing floor. Mr. Thompson graduated from Auburn University in 2008 with a BEng in Aerospace Engineering and has been with Airbus Americas for over 10 years, with half of this time spent in the Oxygen Systems Design Office.

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