

Self-Configuring Hybrid Duct System and Attachment Technologies for Environmental Control Systems

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ABSTRACT

Environmental Control Systems (ECS) ducts on airplanes are primarily fabricated from aluminum or thermoset composites, depending on temperature and pressure requirements. It is imperative to fabricate lightweight, cost effective, durable, and repairable systems with minimal tooling. It is also important that the duct systems are easy to assemble even with alignment issues resulting from structural variations, tolerance accumulation, variation from thermal expansion of different materials, and inherent duct stiffness. These requirements create an opportunity and need for a technology that can address all of these issues, while increasing performance at the same time.

This report provides a background on current ECS ducting systems. It also introduces a new, innovative duct system technology and self-torquing attachment system for use in high temperature and pressure systems with the following characteristics:

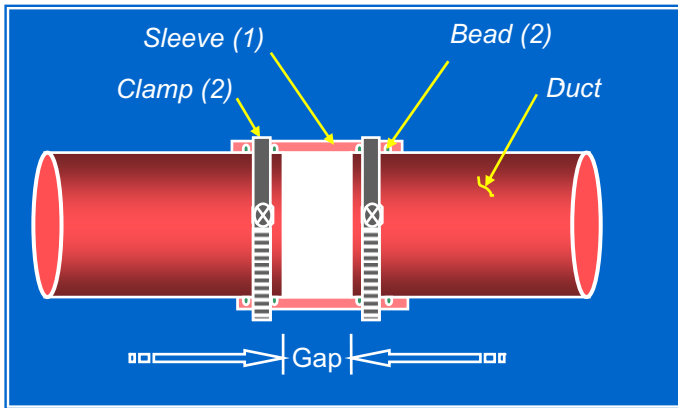
- less than half the weight of current systems it is replacing,
- cost effective,
- environmentally friendly,
- superior durability,
- self-compensating (i.e. flexibility to conform to specific assembly configurations and accommodates factors such as structural variability and expansion), and
- inherent vibration and noise dampening capabilities.

This new technology meets the stringent FAA regulatory flammability and smoke density requirements, and can be used in over 700 aircraft system applications such as: Ram Air, Avionics Cooling, Trim Air, De-icing, Pressurization, Flight Deck Cooling, APU intake and exhaust, Cargo Heating, Passenger Service Unit, and Cabin Air Conditioning.

INTRODUCTION

There are approximately seven hundred (700) ECS distribution system components (ducts/hoses/plenums) in a mid-size airplane representing various systems as stated above. Some of these systems are required to sustain high temperature and pressure and function in a harsh environment, while others supply ambient or conditioned air at much lower temperature and pressure. In addition, each system has to meet certain regulatory flammability and environmental requirements based on its location and function.

Ducts are traditionally fabricated from metals or heavy reinforced composites. However, industry has recently relied on using new generation thermoset composites primarily for weight savings (e.g. a single pound can impact the value of an aircraft by up to \$1200 a year). These ducts are usually located behind the sidewalls, above ceiling panels, below the floor, in unpressurized compartments, wing structure, or within structural components and are not visible to the passengers. They have fixed configurations and are required in multiple sizes to accommodate installation requirements in limited access and space locations.



Duct Connecting System

Figure1

Industry practice is to maintain a gap between adjoining ducts and to connect them with a semi-soft, multi-layered, elastomeric (silicone) coated, fiberglass sleeve (see Figure 1). The reasons for maintaining a gap is to accommodate growth and to enable the sleeve to accommodate misalignment of the two duct components being connected. This connecting system requires beads on each duct end. The beads are intended to provide stiffness to the duct end to tolerate clamp pressure, and also to capture and restrict movement of the sleeve and clamps. The clamp is made from thin, semi-tempered stainless steel. Tie-wraps made from Nylon are sometimes used in place of metal clamps.

CONVENTIONAL DUCT ASSEMBLY - The process and materials for conventional manufacturing and assembly of composite ducts are considered to be expensive and ineffective by the Boeing Corporation and the industry. Conventional ducts are heavier; and expensive to tool, fabricate, assemble, and maintain. Other constraints are briefly discussed below:

- Ducts are generally designed in sizes 6-8 feet long due to fabrication process limitations and handling. This length also helps to avoid obstructions and enables installation through structural frames
- Both metallic and non-metallic ducts require integrated beads at each end to help provide stiffness and to prevent collapse. The beads are raised, rounded, humps in the duct material, around the duct circumference. The beads also help to retain the clamp used to secure the duct joint sleeve
- Duct connections require 5 detail components (i.e. beads on each end of the ducts, a sleeve, and two clamps (one on each end of the sleeve))
- The entire duct and joining system requires wrapping with thermal insulation assemblies consisting of fibrous insulation batting and a cover material. High temperature duct systems (such as pneumatic, trim air, anti-icing, and cargo heat) use a silicone coated fiberglass cloth cover that is rated for

high temperatures, while conditioned air ducts use a fiber reinforced plastic film cover. Breather vents are required in the insulation cover of cold air ducts to prevent ballooning and rupture of the insulation due to pressure changes within the fuselage. The insulation is either taped, or both heat sealed and taped. Some airplanes use foam insulation on cold air supply ducts

- Ducts are often installed under strain due to natural misalignments, structural variations, and accumulated tolerances. This strain can result in leakage from the duct joints and can also shorten its service-life

MANUFACTURING OF METAL DUCTS - Metal forming processes are expensive, inconsistent, labor intensive, and can result in poor quality parts. Causes for these drawbacks are listed below:

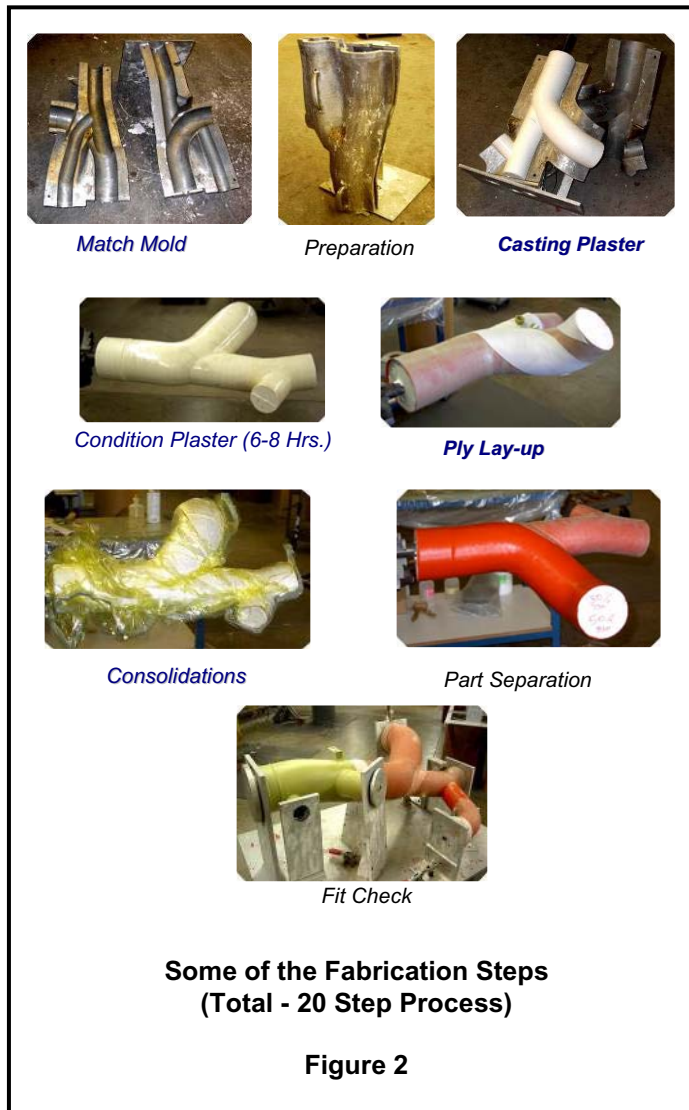
- High tooling cost (impact dies, staging dies, trim jig(s), welding fixture(s)-forming, check fixture(s), heavy maintenance, and set-ups)
- Impact and multi-stage forming
- Welding (multi-piece) and finishing
- High trim loss (over 50% due to oversize material required)
- Multiple trimming operations
- Excessive rework/check due to induced stresses (cold-forming, welding, and trimming)
- Pressure leak tests and sealing
- Surface Preparation/Finishing - smooth surface for sleeve interface to prevent air leaks

MANUFACTURING OF PLASTIC DUCTS - Materials such as Polyetherimide, Nylon, and Lexan are used in limited applications with unique fabrication processes such as: thermoforming, extrusion, rotational molding, and injection molding. The disadvantages of plastics are:

- geometry and size limitations
- required flanges on the sides for bonding
- inconsistent wall thickness (thinning)
- heavy
- low solvent resistance
- stress failure susceptibility,
- process limitations,
- limited acceptability of meeting new regulatory flammability and toxicity requirements
- some of the fabrication processes, such as injection molding and extrusion, require large production quantities to be considered economical.

MANUFACTURING OF COMPOSITE DUCTS - Composite duct fabrication requires an extremely expensive chain of recurring tools (one tool per part) such as special two part molds and repetitive plaster casts. It is also a labor intensive process requiring drying to relieve moisture (6-8 hour oven drying operation), seal coating, conditioning, and application of sloshing

compound to seal material porosity. Some of the major steps are depicted in Figure 2.



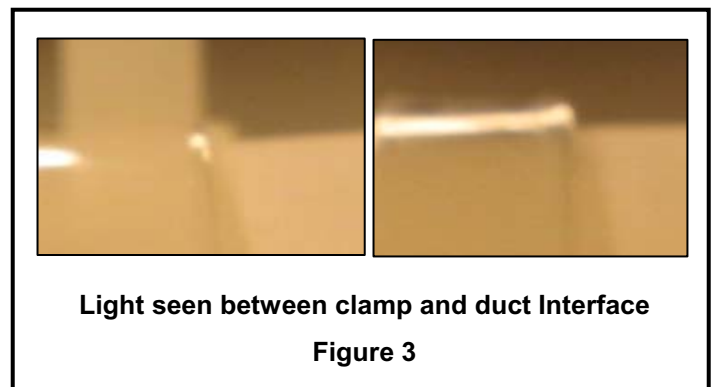
The manufacturing process has the following deficiencies:

- Risk of micro-damage when breaking the plaster mold to separate the cured part
- Effects on part quality due to moisture presence in the hygroscopic plaster (blister, delamination, and lamination)
- Limited to oven curing
- Conditioning process is lengthy and expensive
- Requires pressure leak testing to validate workmanship and any defect repairs are time consuming
- Plaster and composite material waste and disposal cost
- Virtually no tolerance to accommodate variability, misalignments, and expansion
- Size limitations requiring additional assemblies
- Excessive material loss (trimming, sizing, and rejection)

CONVENTIONAL ATTACHMENT SYSTEM - The gap between the connecting ducts can vary from 1-inch to 3-inches. As mentioned earlier, the gap is bridged with an overlapping fiber reinforced, elastomeric (silicone) sleeve, as shown in Figure 1. Although most duct joint sleeves are molded round in configuration, there are cases where non-round sleeves are required to meet unique duct design requirements. Sleeves are available in various thicknesses, diameters, and materials to meet different pressure and temperature applications.

The current methods of connecting duct systems with a sleeve are: (1) mechanical band clamp or tie wrap, (2) adhesive bonding, (3) combination of both. All of these techniques are ineffective, unreliable, and expensive to maintain because of the following attributes:

- Mechanical band clamps and tie wraps fail to provide uniform and consistent pressure, which can cause duct deflection and circumferential changes. It can also result in loss of clamp force, and clamp floating, which eventually leads to leakage (see Figure 3).



- Clamping in a high pressure application can cause weakness at the foot of the clamp, and often results in tear failure of the sleeve
- Band clamps and tie-wraps require special tools to install to a controlled torque. These installation tools require periodic calibration. Also, there are some areas on an airplane where it is extremely difficult to install clamps or tie-wraps due to limited access
- Primer and adhesive application in limited access, or non-visible, areas can result in several anomalies
- Primer usage has the following constraints: uniform application and coverage, adequate drying time, and inspection requirement. The dried primer should be free-of any powdery film, which would be indicative of humidity/moisture exposure
- Adhesive mixing (two part components) requires accurate proportionate volumes to prevent waste
- Primer and adhesive usage requires adherence of application and exposure time limits for achieving optimum bond strength. Bonding must generally be accomplished within 15 minutes to prevent formation of a tack free skin (hardening/filming of adhesive).