Flow Control Device For Axial Flow Turbomachines in Series

Patent #11,585,227

GROW • IMPROVE • LEARN • NETWORK

NAVSEA WARFARE CENTERS PHILADELPHIA

LIBERTY TECH BRIDGE® POWERED BY NAVALX™

DVIRC

Helping Manufacturers Grow Profitably Since 1988

Technology Overview

Flow Control Device For Axial Flow Turbomachines in Series – Patent #11,585,227

The invention relates to the field of generating fluid flow and fluid pressure using a series of axial flow turbomachines. More particularly, the invention presents improvements in the ability of axial flow turbomachinery in series to achieve such flow and pressure without concomitant problems generated by nonuniform flow. Axial flow turbomachinery is used in many applications to generate flow and pressure of fluids (such as water) and gases (such as air). Such axial flow turbomachinery may be present in fans, pumps, compressors, turbines, propellers, impellers, ducted propulsors, waterjets, fluid mixers, windmills, and the like.

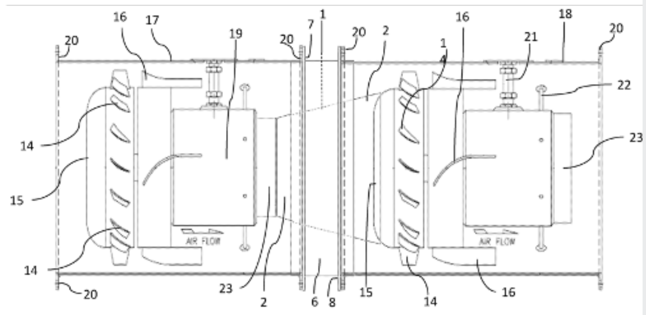


Fig. 9

Flow constrainer **2** topologies include: Cylindrical; truncated conic; parabolic; semi-parabolic; hyperbolic; quadric; ogee; and compound

The flow control device is to be mounted between axial flow turbomachines. It constrains the fluid flow downstream from the first axial flow turbomachine to the periphery between the housing and turbomachine assembly. This way, it directs the fluid flow substantially/completely to the impeller blades of the second turbomachine, while preventing any significant impact of the fluid flow on the center of the second axial flow turbomachine's hub. The invention's flow device thus mitigates and minimizes swirl and other nonuniform fluid flow problems, permitting the turbomachines in series to generate higher pressures. This improves system efficiency, reducing stress on the mechanical members thereof, and minimizing the risk of mechanical failures. The device is also adaptable to provide additional functionality, including using stator vanes to straighten or impart desirable rotational motion to the fluid flow, providing isolation for vibration dampening between the two turbomachines and reducing other undesirable artifacts (e.g., noise and cavitation).

Capabilities

- Mitigates and minimizes swirl and other nonuniform fluid flow problems
- Permits the turbomachines in series to generate higher pressures
- Adaptable to provide additional functionality, including use of stator vanes to straighten the fluid flow or impart desirable rotational motion to the fluid flow
  - Provides isolation for vibration dampening between the two turbomachines
  - Reduces undesirable artifacts such as noise and cavitation

Benefits

- Improves system efficiency
- Reduces the stress on the mechanical members
- Minimizes the risk of mechanical failures

Technology Overview (cont.)

Benchmarks

Benchmarks are unique qualities that are used to compare against existing patents, patent filings, and commercially available products in this assessment tool.

Index Number	Title	Description
1	**Mitigates and Minimizes Swirl and Other Nonuniform Fluid Flow Problems**	**Mitigates and Minimizes Swirl and Other Nonuniform Fluid Flow Problems:** The device constrains the fluid flow downstream from the first axial flow turbomachine to the periphery between the housing and turbomachine assembly, directing the fluid flow substantially/ completely to the impeller blades of the second turbomachine while preventing any significant impact of the fluid flow on the center of the second axial flow turbomachine's hub.
2	**Permits the Turbomachines In Series to Generate Higher Pressures**	**Permits the Turbomachines In Series to Generate Higher Pressures:** It is observed that the air pressure downstream of the second fan is increased beyond that produced by the equivalent pair of axial fans in series without the flow control device proposed in the invention.
3	**Provides Insulation**	**Provides Insulation:** The device is also adaptable to provide additional functionality, including using stator vanes to straighten or impart desirable rotational motion to the fluid flow, providing isolation for vibration dampening between the two turbomachines.
4	**Reduces Undesirable Artifacts Such as Noise and Cavitation**	**Reduces Undesirable Artifacts Such as Noise and Cavitation:** The device is also adaptable to provide additional functionality, including using stator vanes to straighten the fluid flow or impart desirable rotational motion to the fluid flow, reducing other undesirable artifacts such as noise, cavitation, and the like.

Market Research

Executive Summary

This section provides insights into market size, trends, and barriers to entry for commercial applications of the technology, as well as recommendations for deeper market research. Potential markets include cooling for Data Centers, Cleanrooms, and Tiny Homes, as well as Emergency Vehicle Decontamination. The fastest-growing market is Data Center Cooling, with a Compound Annual Growth Rate (CAGR) of 13.76%. Each of these potential markets is quite fragmented, and all have many competing companies and growth potential ahead.

Potential Markets

Data Center Cooling
Refers to the collective equipment, tools, techniques, and processes that ensure an ideal operating temperature within a data center

Market Insights

Market Size

- The global Data Center Cooling market was valued at $10.96 billion in 2022 and is expected to reach $21.42 billion dollars by 2027, (a CAGR of 13.76%).
- • The global Data Center Cooling market is highly fragmented.

Market Trends

- There has been a surge in data centers due to the growing computational requirements by Artificial Intelligence (AI) and media applications.
- Future growth is likely to be fueled by the adoption of edge computing and the increase in Internet of Things (IoT) devices as companies seek to cut costs on high-end customized cooling.
- With increasing capacity and IT equipment density, there is an increasing need for energy-efficient cooling.
- Technology benefits and government support (through the imposition of efficiency regulations on data centers) are expected to fuel growth.
- The adoption of liquid cooling in data centers is increasing, but the fear of failure and spills can limit this adoption.

Barriers to Entry – High

- Intensive investment and competition
- Highly consolidated industry

Key Players

- Daikin Industries Ltd. Schneider Electric S.E., Mitsubishi Electric Corporation, Johnson Controls International plc, and Asetek, Inc.

Market Research (cont.)

Potential Markets	Market Insights
Cleanroom Technology Unidirectional air flow and filtration to strictly control temperature, cleanliness, and humidity	**Market Size** • The global Cleanroom Technology market size was valued at $4.0 billion in 2020 and is expected to increase at a CAGR of 5.4% from 2021 to 2028. **Market Trends** • Increased demand for quality products that comply with regulatory standards—coupled with the technological and economic benefits of these technologies—drives growth. • Benefits such as customized solutions, reduced production time and cost, and improved product flow between cleanrooms are additional factors driving demand. • Equipment is expected to be the fastest-growing segment, owing to the growing use of Heating Ventilation and Air Conditioning (HVAC) systems, laminar airflow units, air showers, air diffusers, fume hoods, desiccating cabinets, pass-through systems, and air filtration systems. • End users of this market are the Pharmaceutical-, Medical Device-, and Biotechnology industries, as well as Hospitals and Diagnostic centers. **Barriers to Entry – High** • Barriers include the cost of cleanroom implementation (including HVAC as a critical component). **Key Players** • Clean Air Products, Kimberley-Clark, DuPont, Terra Universal, and Labconco
Tiny Home HVAC Includes wall units and ductless mini split air conditioners	**Market Size** • The global Tiny Homes market is expected to reach $6.9 billion by 2029 (a CAGR of 3.5% from 2022 to 2029). **Market Trends** • The increasing popularity of tiny homes among tourists is an important market driver. • Rising inflation—leading to increasing living costs—is expected to propel the Tiny Homes market. **Barriers to Entry – Medium** • The price of implementing the Flow Control Device, along with the size of the technology, serve as barriers to entry. **Key Players** • Skyline Champion Corporation, Nestron, The Tiny Housing Co., The Qube, and Timbercaraft Tiny Homes

Market Research (cont.)

Potential Markets	Market Insights
Emergency Vehicle Decontamination Includes vehicle cleaning and vehicle disinfection of emergency vehicles (e.g., ambulances, fire trucks, and police cars).	**Market Size** • The Emergency Vehicle Decontamination market is expected to expand at a CAGR of 9.2% from 2023 to 2030. **Market Trends** • The Emergency Vehicle Decontamination market has expanded rapidly due to advances in technology, increasing demand for innovative solutions, and the growing importance of automation in various sectors. • As a result, the market has become highly competitive. • The Covid-19 pandemic led to an increase in demand for vehicle decontamination; the Flow Control Device's effectiveness at moving air quickly from one area to another may make it a fit for this use case. **Barrier to Entry – Medium** • The primary barrier to entry is the cost of R&D remaining to incorporate decontamination solutions into emergency vehicles. **Key Players** • KARCHER, SEI Industries Ltd., The Patron Group, Polygon Group, and Rosenbauer

Market Research (cont.)

Conclusions

- The Data Cooling Center market will remain an attractive market for the Flow Control Device if the technology can be tested and proven to increase cooling efficiency.
- Cleanroom Technology is another viable market. The need for efficient HVAC in cleanrooms is critical, and the growing need for hyper-clean environments (in the medical and semiconductor industries in particular), drive the need to remove airborne particles.
- Tiny Home HVAC involves strict footprint and energy limitations; this industry may not be as applicable as some others.
- The Emergency Vehicle Decontamination market could be a potential end use for the Flow Control Device, due to its ability to provide necessary airflow and remove hazardous material. **Note:** It is crucial that the device implementation be feasible in the space already allotted for the ventilation on the vehicle.

Recommendations – Rough order of Magnitude (ROM)

Priority Key:

- **Must:** A critical and time sensitive recommendation to advance technology with respect to the area of focus.
- **Should:** An important recommendation to advance technology but is dependent upon predecessor recommendations or is not time sensitive.
- **Could:** A recommendation that will have insignificant impact on advancing the technology but could be a beneficial consideration.

Recommendations	Priority	ROM Cost	ROM Timeline
Advance TRL and MRL Plan	2	$15,000	4 months
Market Planning and Scouting	3	$35,000	6 months
License technology	1	$15,000	2 months
ROM Total:		**$65,000**	

Level of Market Opportunity

Analyst: DVIRC

Technology Viability Assessment
Powered by Miltech

Competitor Analysis

Competitor Analysis Intent

The intent of this section is to identify potential commercially available, competing technologies and provide conclusions and recommendations based on the information provided at the time of assessment. The resulting information may be used to identify technology strengths or weaknesses in features or claims, as well as potential licensing partners.

Research Methods

Various resources to uncover information about different companies that perform similar functions

Markets	Competitors
Data Center Cooling	• **IBM CoolBlue:** Optimizes the power consumption, management, and cooling of infrastructure.
Cleanroom Technology	• **Clean Air products: Clea**nroom Fan Filter Units (FFUs) are self-contained systems that use HEPA filtration technology. • **ClimaTemp:** Mechanical contracting firm specializing in residential, commercial, and industrial HVAC. • **Air Innovations:** Features an entire division dedicated to the design and manufacture of unitary and custom HVAC systems for cleanrooms and critical environments. • **Green Revolution Cooling:** Transforms data floorspace from an average of 100-200 watts to 2,200 watts per square foot, with rack densities up to 184 kW, all while reducing OEM server power intake.
Tiny Home HVAC	• **AMANa: 5**,000 BTU window-mounted air conditioner quickly cools a room up to 150 square feet. • **PTAV4LESS:** New 15,000 BTU PTAC Unit by Frigidaire; 208/230 volts, 30 amps. • **GE Appliances:** 10,000 BTU Inverter; smart, ultra-quiet window air conditioner cools medium rooms up to 450 square feet
Emergency Vehicle Decontamination	• **Puradigm:** HVAC air purifier system integrates air purification technology with existing heating & air conditioning. • **Plasma Air:** 600 series, needlepoint, brush-type ionizers produce an equal amount of positive and negative ions to neutralize harmful pollutants and odors. • **Filt Air Ltd:** GTS terminal; high-efficiency filter is designed and tested to extract the smallest particles out of the air.

Competitor Analysis (cont.)

Markets	Competitors
	Substitutes
Liquid Cooling	• **Iceotope:** Precision liquid-cooling solutions offer extreme cooling performance while isolating and protecting critical IT from the surrounding environment and atmosphere. • **Precision Emerging Cooling:** Computer Room Air Conditioners (CRAC) Direct Expansion (DX) are a compact solution for efficient cooling in small spaces. • **Schneider Electric:** Liquid-cooled, all-in-one prefabricated module delivers an innovative, fast, and flexible solution to enable high-performance processing and security at the edge, shorten deployment time, and improve cost and performance predictability.
Geothermal Cooling	• **Calpine** • **Ormat Technologies Inc.** • **Enel Green Power**
Solar Cooling	• **Advanced Cooling Technologies:** Premier thermal management solutions company, focusing on custom applications of two-phase heat transfer technology. • **Sympower: Online** software platform seamlessly integrates with heating, cooling and ventilation systems through a lightweight technology that can restore the balance on the electricity grid. • **Sure chill:** Doesn’t need a constant power source; on-grid situation with intermittent power.
Kyoto Cooling	• **Kyoto Cooling:** KyotoWheel provides 90% effectiveness in heat rejection to produce and maximize constant free cooling hours in data centers.
Evaporative Cooling	• **Tower Tech:** Cooling towers significantly reduce owners’ operating costs, offering superior maintenance and safety characteristics. • **ABCO HVACR Supply & Solutions:** Full-line distributor of HVAC and refrigeration systems. • **Thermal Car, Inc.:** Manufacturer of standard and custom, closed-loop adiabatic fluid coolers.

Conclusions

The markets indicate the ways this invention can be used and implemented to produce improved results.
The primary substitute is liquid cooling technology, which has seen significant development and can produce better results than regular HVAC.

Technology Readiness Level – Hardware

Technology Readiness Level Intent	Current TRL
The intent of this document is to determine the level of effort required to advance the technology from its current state to a desired future state. Project tasks may be proposed to assist in technology advancement. The *Technology Readiness Level (TRL) Deskbook* version July 2009 served as the reference document for the TRL assessment. TRLs run from 1 to 9.	**4**

Research Methods

TRL determination has been conducted on applicable levels as seen below. The assessment was conducted by reviewing the following materials:

- Technology Overview
- Patent No. 11,585,227
- Q&A call with inventor

Findings

The Flow Control Device for Axial Flow Turbomachines In Series constrains fluid flow downstream from the first axial flow turbomachine to a second turbomachine, while preventing any significant impact of the fluid flow on the center of the second axial flow turbomachine's hub. The device mitigates and minimizes swirl and other nonuniform fluid flow problems, permitting turbomachines in series to generate higher pressures. This improves system efficiency, reducing the stress on the mechanical members and minimizing the risk of mechanical failures.

The technology is TRL 4; a CAD file exists, proof of concept has been fabricated, and preliminary benchtop testing measured the flow rate and proved efficacy of a functional prototype. Next steps include computer modeling to validate the calculations behind the various cases. For general application, 10% of the device is comprised of commercial-off-the shelf (COTS) gaskets, bolts, etc., and the rest is to be custom manufactured. Although there is neither a defined Technical Data Package (TDP) nor a Bill of Materials (BoM), the CAD drawing was sufficient for a machine shop to fabricate the prototype for approximately $3,500.

Conclusions

For the Flow Control Device for Axial Flow Turbomachines In Series to advance its TRL, the prototype must be validated in an operational environment. The device would be useful anywhere there are two fans in series, especially one with limited space. Creation of a TDP and BOM for the invention would also be important for advancing the TRL to prepare for manufacturing, although both could vary slightly depending on the application. Confirming suppliers and manufacturers will also be essential. Further testing and development with the specialized topologies, as well as confirming the device manufacturability are necessary.

Technology Readiness Level – Hardware (cont.)

Recommendations

Priority Key:

- **Must:** A critical and time sensitive recommendation to advance technology with respect to the area of focus.
- **Should:** An important recommendation to advance technology but is dependent upon predecessor recommendations or is not time sensitive.
- **Could:** A recommendation that will have insignificant impact on advancing the technology but could be a beneficial consideration.

Recommendations to advance TRL to 9	Priority	ROM Cost	ROM Timeline
Develop TDP	Must	$3,000	2 months
Develop Cost Model	Must	$1,000	1 month
Complete Design for Manufacturing	Should	$5,000	4 months
Study necessary compliance approvals/accreditations	Must	$4,000	3 months
Discuss potential to license technology to OEMs	Could	$2,500	2 months
Finalize Cost Model	Should	$1,500	1 month
Third party TRL revision	Could	$3,500	2 months
Finalize TDP	Should	$2,000	1 month
Rough Order of Magnitude (ROM) Total		**$22,500**	**12-15 mos.**

Analyst: DVIRC

Technology Viability Assessment Powered by Miltech

Manufacturing Readiness Level

Manufacturing Readiness Level Intent	Current MRL
The intent of this assessment is to determine the level of effort required to advance the technology from its current state to desired future state. Project tasks may be proposed to assist in the advancement of the technology. The *Manufacturing Readiness Level (MRL) Deskbook* version 2.0 served as the reference document for the MRL assessment. MRLs run from 1 to 10.	**4**

Research Methods

Although a contractor has not been identified, an MRL determination has been conducted on applicable levels as seen below. The assessment was conducted with the following events and materials:

- Technology Overview
- Patent No. 11,585,227
- Q&A call with inventor

Findings

The following is an assessment of the technology's current MRL and reasoning for the rating. The Flow Control Device For Axial Flow Turbomachines In Series has a functional prototype, proving the capability to produce a working system in a laboratory environment and categorizing the device as MRL 4. A prototype of the device has been tested with hand instrumentation to measure the flow rate and prove efficacy.

All elements of the Flow Control Device may be fabricated from a variety of materials for different applications. These include, but are not limited to: metal, plastic, rubber, resin, polymer, and carbon fiber. In some embodiments of the present invention, all elements are constructed from the same material; in other embodiments, the flow constrainer, outer ring, and struts may each be fabricated from different materials. In some embodiments, it may be desirable to control system vibration. Optional boots may be attached to the device flanges on the sides facing the housings to provide vibration dampening. Such boots may be constructed from rubber, formable viscoelastic polymer, or other vibration-damping material.

In general, the device does not require any exotic materials and can be constructed through stamping and welding, or even 3D printing. Flange gaskets are also important, but these are neither special nor exotic. To achieve desired flow rates, different types of topologies, (cylindrical, compounds, etc.), could require custom manufacturing capabilities. The level of topology complication may dictate the potential need for specialized technologies, but none of these are anticipated to be prohibitively difficult. Software might also be integrated to control the device fans, which will require the presence of power and a microcontroller. The software has not been created yet; more computation and testing of different designs will be required before finalization.

There is no current cost model, but the prototype had been quoted at a value of approximately $3,500 dollars by a local machine shop. For general application, 10% of the device is comprised of commercial off the shelf (COTS) gaskets, bolts, etc. The rest is manufactured by traditional means unless a use case for specialized topologies requires custom manufacturing. There are no foreseen approvals or certifications, although that could change based on the industry application.

Manufacturing Readiness Level (cont.)

Conclusions

Until the TRL process (TDP, BoM, testing) is advanced, the MRL will remain low. Further prototype development for specialized topologies and validation in an operational environment will be a crucial next step. Prototype aerodynamic analysis will be needed, and topology should be adjusted based on those outcomes. In terms of production level first article testing, shock and vibration testing would be critical.

It is recommended that the inventors finalize suppliers (including possible backups) to widen sourcing options for COTS parts and avoid supply chain issues. A more thorough MRL assessment should be completed when these suppliers have been identified and an evaluation can be made in a production environment.

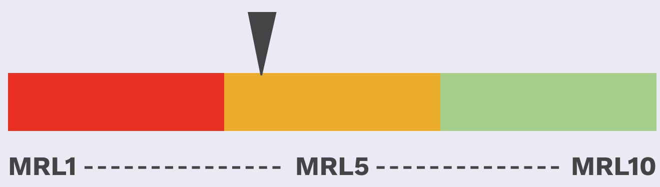
Manufacturing Readiness Level (cont.)

Recommendations

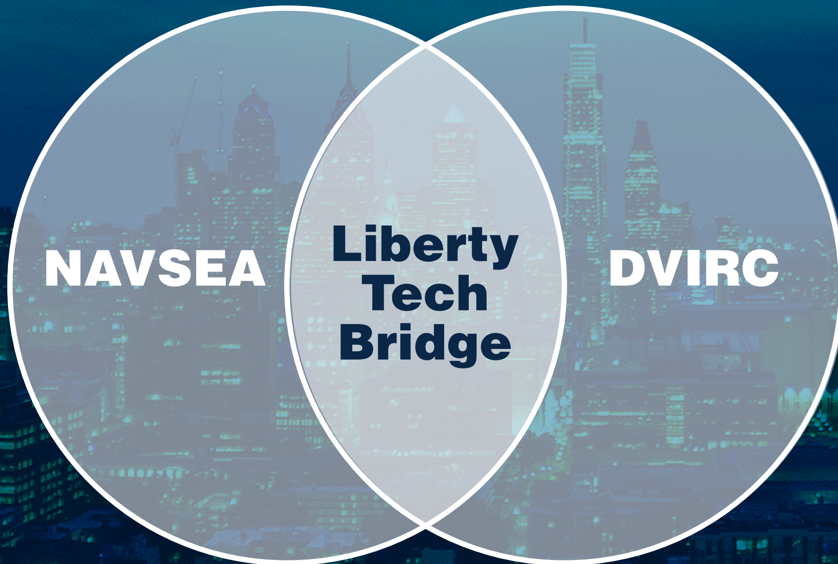
Priority Key:

- **Must:** A critical and time sensitive recommendation to advance technology with respect to the area of focus.
- **Should:** An important recommendation to advance technology but is dependent upon predecessor recommendations or is not time sensitive.
- **Could:** A recommendation that will have insignificant impact on advancing the technology but could be a beneficial consideration.

Recommendations to advance MLR	Priority	ROM Cost	ROM Timeline
Develop BoM	Must	$3,000	2 months
Develop Cost Model	Should	$1,500	1 month
Scout assembly/COTS suppliers	Must	$2,000	2 months
Perform Critical Design Review	Must	$2,000	1 month
Complete Design for Manufacturing	Should	$5,000	4 months
Discuss potential to license technology to OEMs	Could	$2,500	2 months
Finalize Cost Model	Should	$1,500	1 month
Finalize BoM	Should	$1,500	1 month
Third party MRL revision	Could	$3,500	2 months
Finalize/Select assembly/COTS suppliers	Must	$1,000	1 month
Pilot Production Run	Must	$3,500	1 month
Evaluation and Design Modification	Must	$2,500	1 month
Full-Rate Production Run	Must	TBD	TBD
ROM Total:		**$21,500**	**14~16 mos.**



Analyst: DVIRC



The result of an innovative partnership between the Naval Surface Warfare Center Philadelphia Division (NSWCPD) and the Delaware Valley Industrial Resource Center (DVIRC), Liberty Tech Bridge seeks to strengthen ties between the region's defense and industrial sectors. Together, NSWCPD and DVIRC are accelerating and expanding competitiveness among America's warfighters.

DVIRC

2905 Southampton Road
Philadelphia, PA 19154

215-464-8550
info@dvirc.org
www.dvirc.org

/DVIRC_PA
/dvirc.sepa
/company/dvirc/
/user/dvirc