International Space Station (ISS) Bacterial Filter Elements (BFEs): Filter efficiency and pressure testing of returned units

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Objectives

Develop test protocol for ISS particulate filters and extending both operating and shelf life

Perform penetration and pressure drop testing of ISS filters returned to Earth replaced under 2 different replacement intervals.

Long-term objective:

- Extend filter test protocols for acceptance testing and inventory testing for future manned spacecraft exploration programs

International Space Station

ISS is an orbiting laboratory weighing 925,000 lbs and measures 361 ft end-to-end (approximate length of a football field).
ISS has an internal pressurized volume of 32,333 cubic feet ~ equal to a Boeing 747.

Introduction/Background

The ISS Bacterial Filter Elements (BFEs) are HEPA-grade filters utilized on ISS to control particulates in the pressurized volume.

- Total of 21 BFEs installed in US segment. Columbus and JEM use HEPA filters of a different design
- The BFEs see an replacement interval between 2-5 years; replacement interval varies by location.
- On-orbit maintenance consists of frequent vacuuming.

ISS BFEs were delivered in several lots and are reaching the end of their "use life".

- Filters were supplied United Technologies Aerospace Systems (UTAS), in two phases: 1997 thru 1999 and 2003 thru 2004.
- As of 2013, approximately 54 units had reached the end of their "use life" where:
  - use life is defined as in-service life + shelf life
- Recently, filter use life extended from 10 to 22 years, based on testing of 7 filters removed from controlled storage.

Potential failure mechanisms for stored filters are:

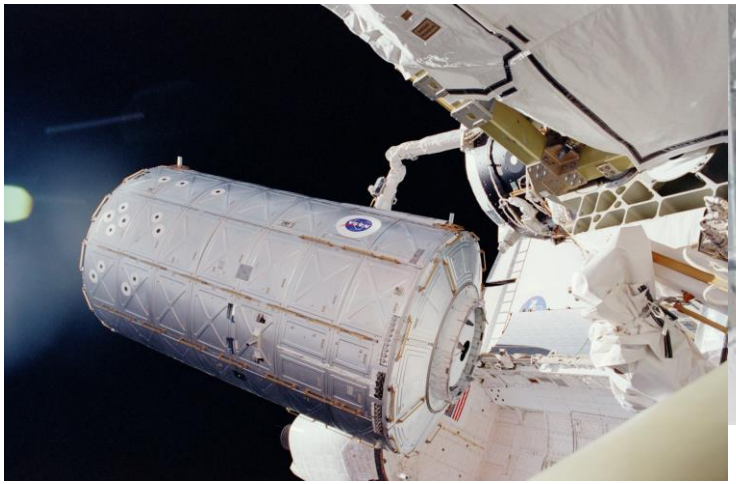
deterioration of the resin binder in the media,

oxidation or loss of volatile constituents in the sealing adhesive

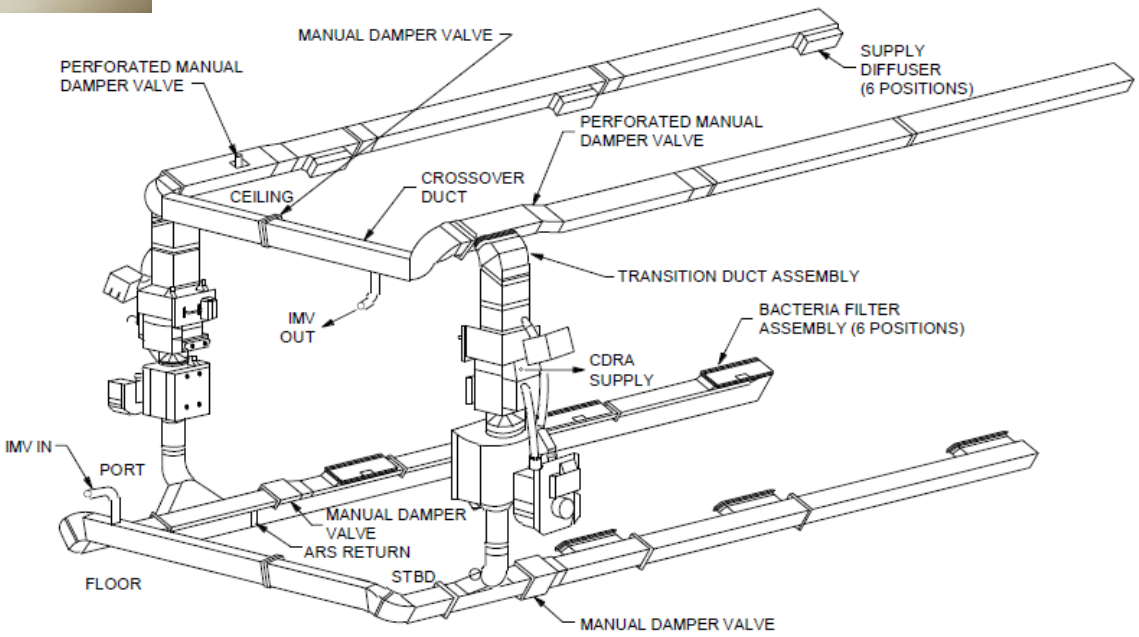
crystallization of the glass fiber media

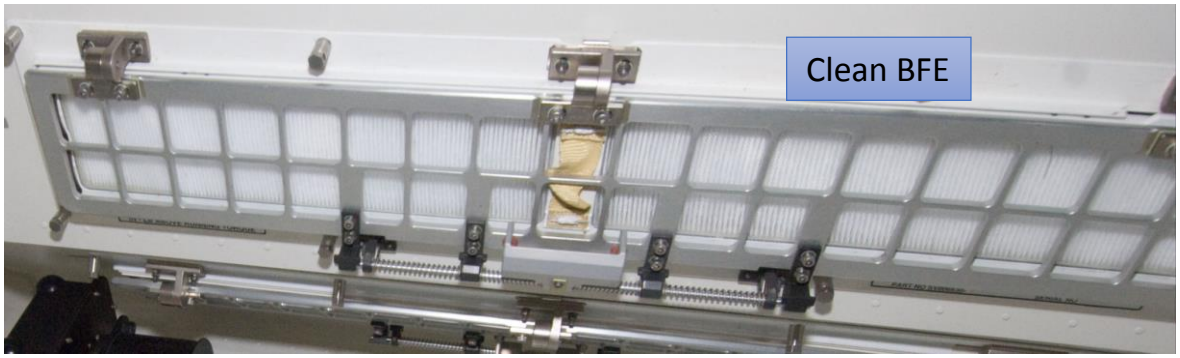
With ISS design life extended to 2024 (and potentially to 2028), there is a need to address ISS BFE inventory, and from a more general perspective, develop the test methodology for testing and evaluation of filters to be utilized for future long-duration missions.

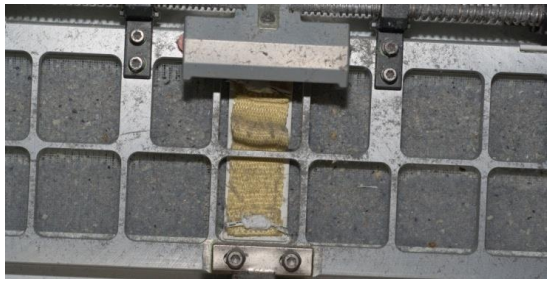
Example: ISS LAB module ventilation system



- ISS Lab module volume is 3834 ft^3.
- Required ventilation flow rate is 400 cfm.
- 6 BFEs installed in ventilation system.

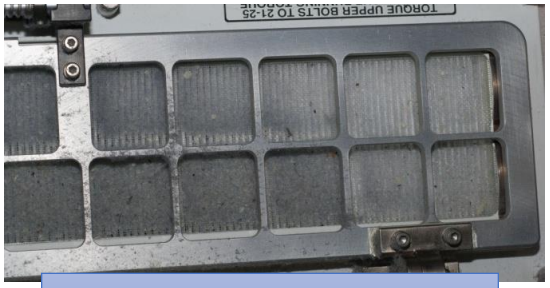






8 days accumulation

12 days accumulation



Node 3
Hygiene & Exercise Location

Filter standards

Mil-Standard 282 is the first HEPA filter standard developed based on a thermally generated Di(2-Ethylhexyl) Phthalate (DOP) smoke cloud as the challenge aerosol.

- Hi-efficiency filtration became of interest to the military, after World War I, in order to protect troops from poisoned gas attacks

Institute of Environmental Sciences and Technology's **IEST-RP-CC001.5** specification is an overall standard describing the types of HEPA filters (Types A thru K) and construction materials and requirements, but also describes the performance requirements (e.g. filter resistance or pressure drop) and need to perform both efficiency and leak test as part of penetration testing.

IEST-RP-CC034.3 specification discusses the HEPA leak testing, in particular, the choices of tests, aerosol oils, and recommended test procedures and scan test methods, uniformity of the challenge aerosol, and guide for aerosol particle detector which is dependent on filter type.

IEST-RP-CC007.2 provides similar test methodology for Ultra Low Penetration Air (ULPA) filters, not the subject of this paper, but does provide the component breakdown of typical filter test systems and appropriate recommendations.

ASHRAE 52.2-20 is a test method standard for the broader air filter application area, and not just restricted to HEPA and ULPA filters; applicable to our application are the requirements for air velocity and aerosol distribution uniformity of the test measurement system.

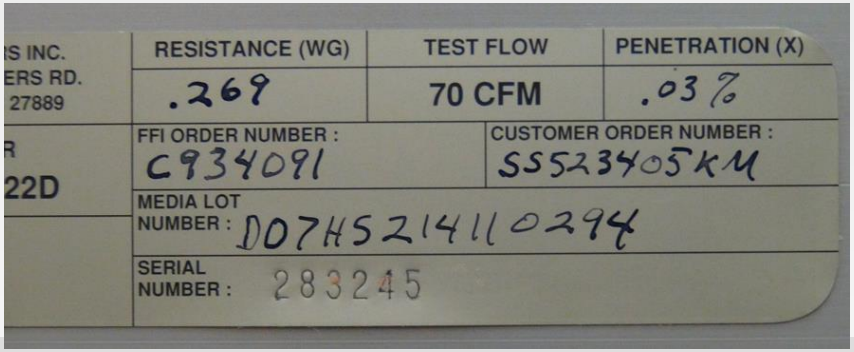
ISS Bacterial Filter Element (BFE)

ISS filters are bacterial filter elements (BFE) and contain pleated borosilicate HEPA media

- Rectangular aluminum frame with outside dimensions of 29” x 4” x 4.375”.
- Filter media is covered with a 20-mesh (0.84-mm clear opening) prescreen (Nomex™) at the inlet and an aluminum mesh screen at the outlet.

ISS filter specification:

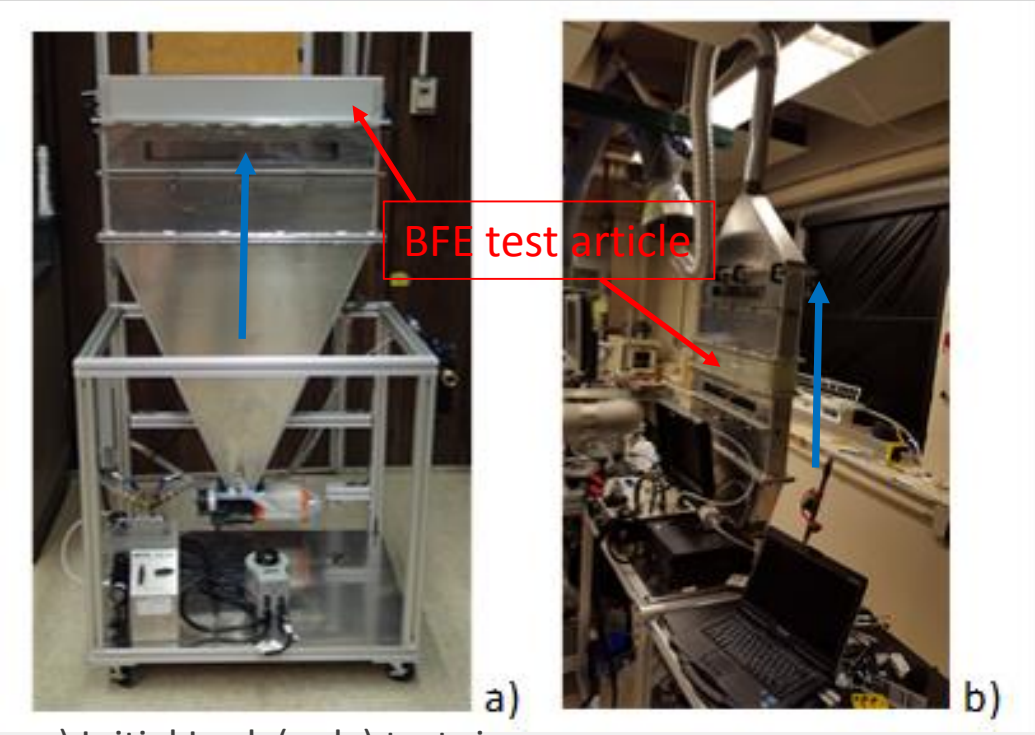
- Efficiency of 99.9% @ 0.3 microns @ 70 CFM (HEPA-grade efficiency is 99.97%)



Test Setup

Designed and fabricated upright test duct for unique BFE cross-section.

- Tapered inlet section (aerosol injected at base)
- Blower mounted upstream
- Venturi meter used for flow measurements
- Conic section downstream of test article to allow for proper mixing prior to penetration measurement

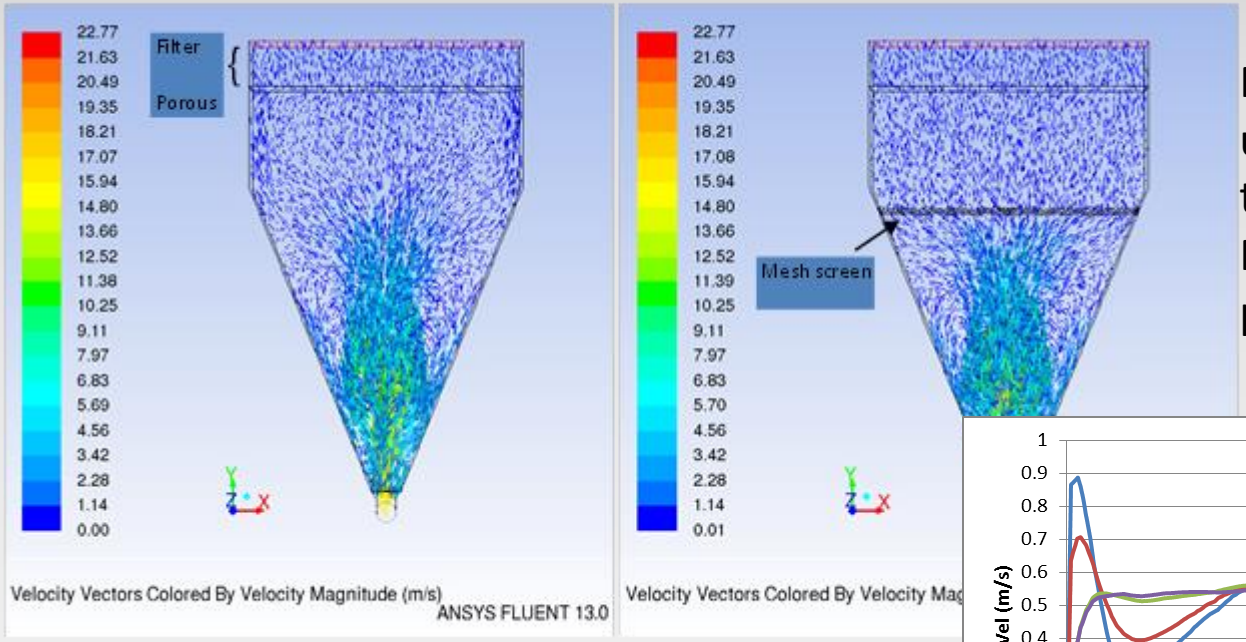


a) a) Initial Leak (only) test rig

b) b) Modified test rig for penetration/pressure drop testing

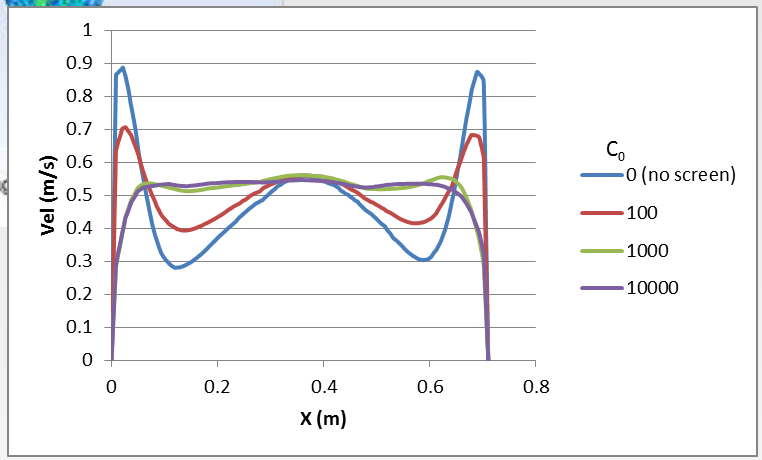
c) Blue arrows indicate direction of air flow.

Test Duct design



(a)

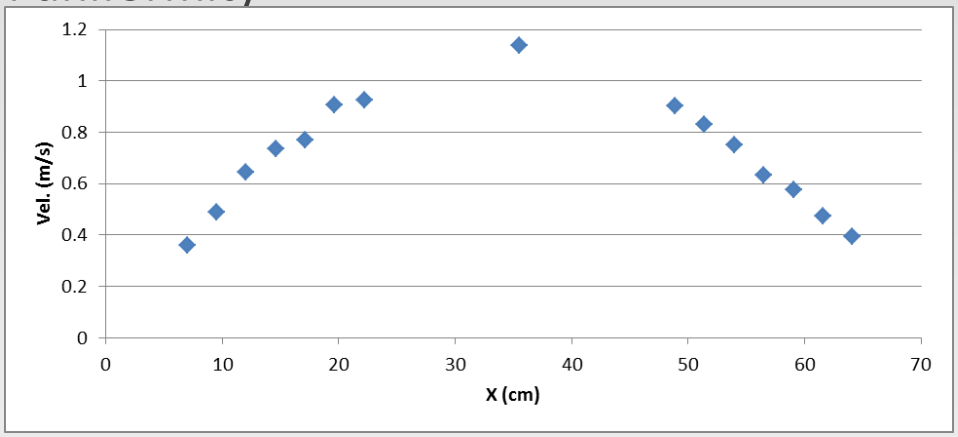
Performed 3D CFD analysis using FLUINT with κ-ε turbulence model. Filter modeled as a porous zone.



Analysis concluded that an added mesh screen In tapered portion of duct provides a more uniform velocity profile.

Flow and aerosol distribution measurements

Filter standards specify ± 10% flow variation and ± 15% variation in aerosol uniformity



Air velocities were measured with a hot wire anemometer.

Qualitatively evaluated aerosol uniformity with a handheld laser. Later, made photometer measurements at 15 locations along filter cross-section. Variation in concentration < 10%.

Pressure Drop and Penetration results

Total of eight BFE filters tested:

6 Returned BFEs:

Varied in time in continuous operation from 0.8 years to 2.5 years

- i.e. 4 followed early 1 year replacement interval, 2 were on revised 2.5 year replacement interval.

2 Engineering Development Units (EDUs):

- These saw very limited time in operation (were installed for LAB module check-out on the ground; operated in a clean room).

NOTE: Small sample set due to limitations on payload down-mass (i.e. how much “stuff” can be returned from ISS to Earth).

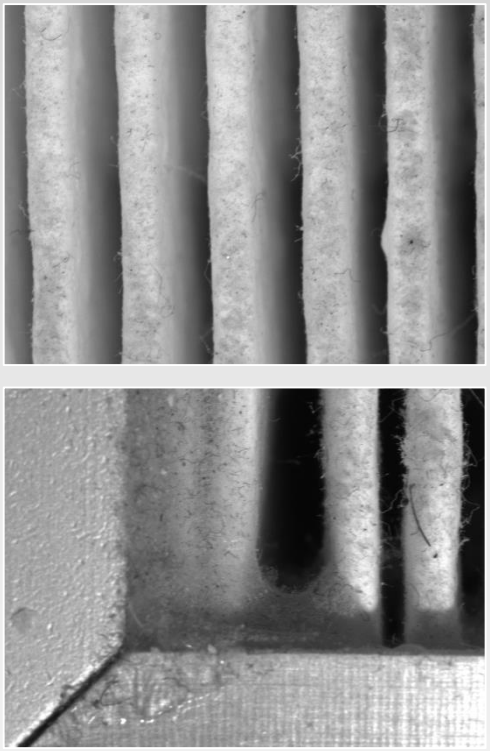
Visual inspection prior to testing

BFE filter unpacked and visually inspected for damage.

Any large loose clumps of debris (mainly lint) were removed with a tweezers

Nomex screen removed for testing (to achieve tight seal on inlet test duct)

One BFE tested for active biological content. (low)



Images of the BFE S/N 0153 HEPA media. The images cover an 18.4 mm × 12 mm area. a) Inlet pleat edges near middle of cross-section; b) Corner of inlet surface including aluminum frame and adhesive.

Pressure drop and penetration results

BFE TYPE	SERIAL NUMBER	Time in service	PRESSURE DROP		PENETRATION	
			Initial (in WC)	Tested (in WC)	Initial (%)	Tested (%)
Returned	0148	911 days/2.5 yrs	0.29	0.386	0.01	0.0104
Returned	0153	911 days/2.5 yrs	0.30	0.454	0.01	0.0558
EDU	XSR08	ground testing only	0.269	0.310	0.03	0.0245
EDU	XSR09	ground testing only	0.276	0.290	0.01	0.0058
Returned	0009	299 days/0.8 yrs	0.29	0.303	0.02	0.0142
Returned	0093	334 days/0.9 yrs	0.27	0.285	0.01	0.0088
Returned	XSR04	334 days/0.9 yrs	0.262	0.264	0.01	0.0137
Returned	XSR05	334 days/0.9 yrs	0.274	0.272	0.01	0.0126

Pressure drop test results

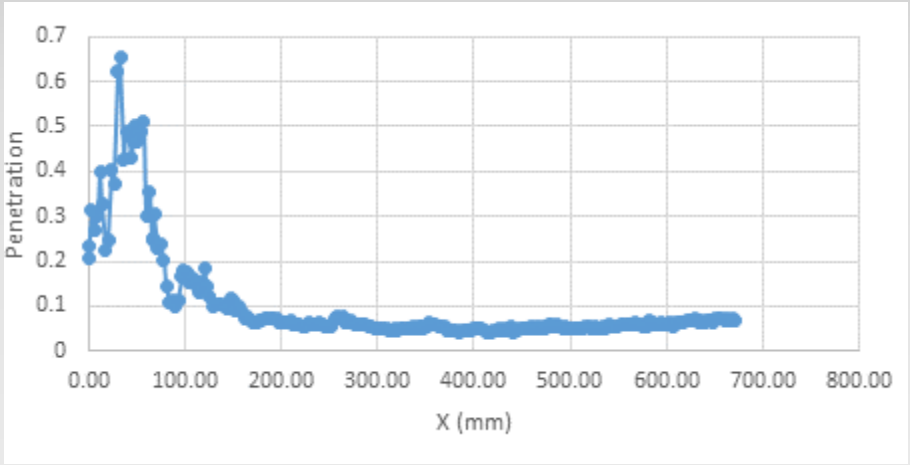
- All BFEs met end-of-life pressure drop requirement.
- All BFEs met the particulate removal efficiency requirement of 99.9%, although measured penetration increased for S/N 0153.

Leak test results

BFE TYPE	SERIAL NUMBER	PENETRATION	
		Flow = 70 cfm (%)	Flow = 14 cfm (%)
Returned	0148	0.0104	0.0079
Returned	0153	0.0558	0.0146
EDU	XSR08	0.0245	———
EDU	XSR09	0.0058	———
Returned	0009	0.0142	0.0024
Returned	0093	0.0088	0.0000
EDU	XSR04	0.0137	0.0000
EDU	XSR05	0.0126	0.0000

- First stage leak test (measured penetration at 20% of design flow).
- All BFEs passed except S/N 0153 (did not measure one order magnitude drop in penetration).
- Performed second stage leak test only on S/N 0153.

Second stage Leak test result



- Performed second stage leak test only on S/N 0153
  - Linearly scanned entire filter cross-section by sweeping the aerosol photometer probe at approximately 1-2 cm/sec.
  - Detected leak but was unable to find protrusion via visual inspection.
  - SIDE NOTE: Observe increase in penetration near edges when manually scanning filters. May be exacerbated by larger perimeter to cross-sectional area?

Conclusions

A test duct system was designed to test the unique cross-section ISS Bacterial Filter Elements (BFEs).

The results showed that all BFE test articles tested exceed the ISS requirement for overall efficiency of 99.9% minimum for 0.3 micron particles for several replacement intervals.

All returned BFEs met the end-of-life pressure drop requirement (0.5 in WC), although one of the BFE replaced at the extended 2.5 interval. It had a measured value of 0.45 in WC.

These techniques for characterizing the test duct and perform leak testing can potentially be applied to conducting acceptance testing and inventory testing for future manned exploration programs with air revitalization filtration needs, possibly even for in-situ filter element integrity testing for long-duration missions.