Ballast Water Sampling using Proportional Flow Control: Evaluating the Utility of External Ultrasonic Flow Meters in the Shipboard Environment

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Outline

- Background – ballast water discharge standards; compliance and representative sampling
- Technical challenges – maintaining proportional sample flow rates
  - Measuring main ballast flow rates
- Experimental approach – validation testing using ultrasonic external flow sensors to measure main ballast flow rate and maintain proportional sample control

Ballast Water Sampling

- In the U.S., sampling and analysis for living organisms in type approval testing will be in accordance with the Environmental Technology Verification Program Protocol (ETV; EPA 2010; USCG 2012)

Representative Sampling

- Per the ETV Protocol - samples must be drawn such that they are "representative" of the water being sampled (EPA 2010)

below. In any case, validation of the Test Facilities configuration should include verification that the chosen sampling design, geometry and installation result in representative samples and minimize organism mortality as a result of sample acquisition.

Protocol for the Verification of Ballast Water Treatment Technologies Version 5.1 — *September 2010*

Recommendations for the design and installation of appropriate sampling facilities are given below. In any case, validation of the Test Facilities configuration should include verification that the chosen sampling design, geometry and installation result in representative samples and minimize organism mortality as a result of sample acquisition.

5.3.2.5 Design of In-line Sampling Apparatus

Through computational fluid dynamics modeling, it has been shown that the isokinetic diameter calculation can provide guidance for sizing of sample ports for sampling of organisms (Richard et al., 2008). Simulations showed that flow transitions from the main stream were best for sample port diameters between 1.5 and 2.0 times the isokinetic diameter. Ports sized in this range had smooth transitions and pressure profiles that allowed for direct sampling without the need of a pump to induce sample collection. The isokinetic sample port diameter should therefore be determined generally according to the equation:

$$D_{iso} = D_m\sqrt{\frac{Q_{iso}}{Q_m}}$$

Representative Sampling

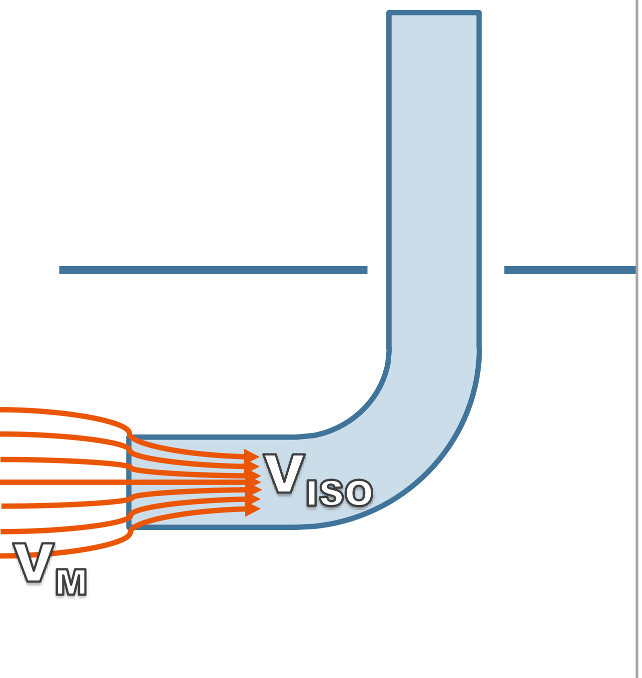
- The sample port should be sized based on the isokinetic diameter (D_{ISO})
  - Where velocity entering the sample port (V_{ISO}) equals velocity in the line being sampled (V_M)
- From the ETV Protocol:
  - D_{ISO} is dependent on the main ballast pipe diameter (D_m), sample volumetric flow rate (Q_{iso}), and main volumetric flow rate (Q_m):

$$D_{ISO} = D_m * \sqrt{\frac{Q_{iso}}{Q_m}}$$

Isokinetic Sampling

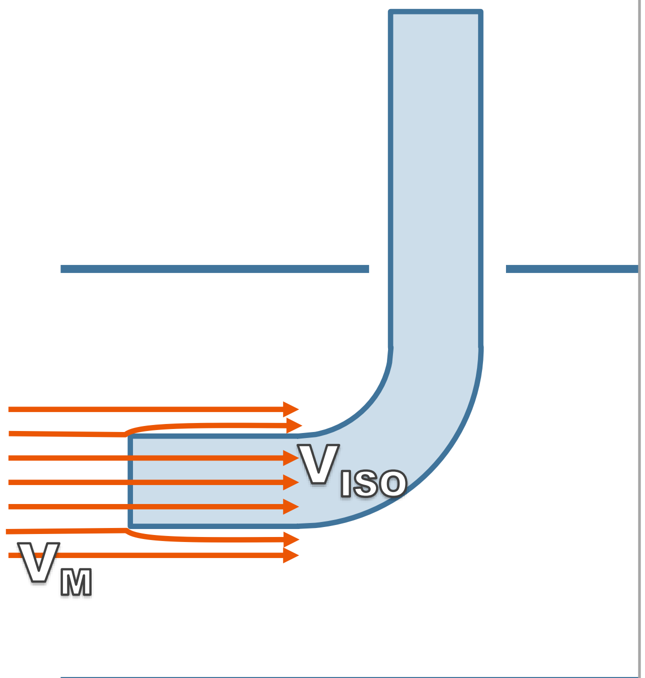
Super-Isokinetic

$V_{iso} > V_M$



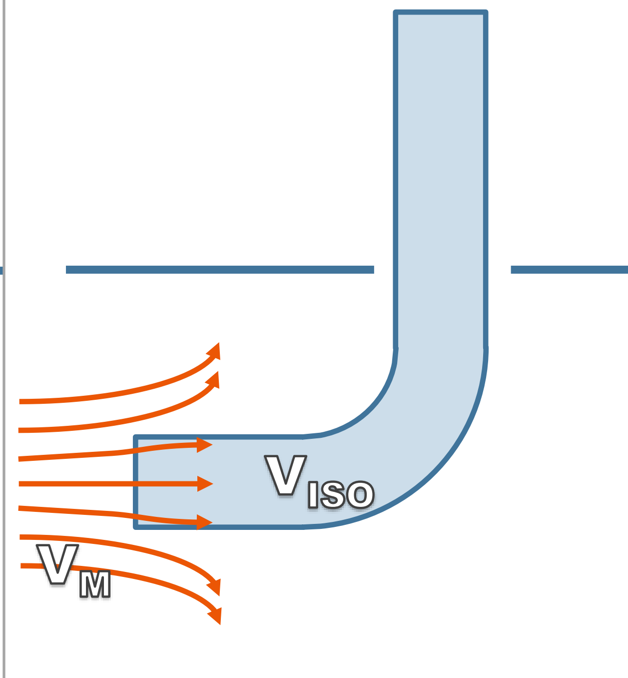
Isokinetic

$V_{iso} = V_M$



Sub-Isokinetic

$V_{iso} < V_M$



Isokinetic Sampling

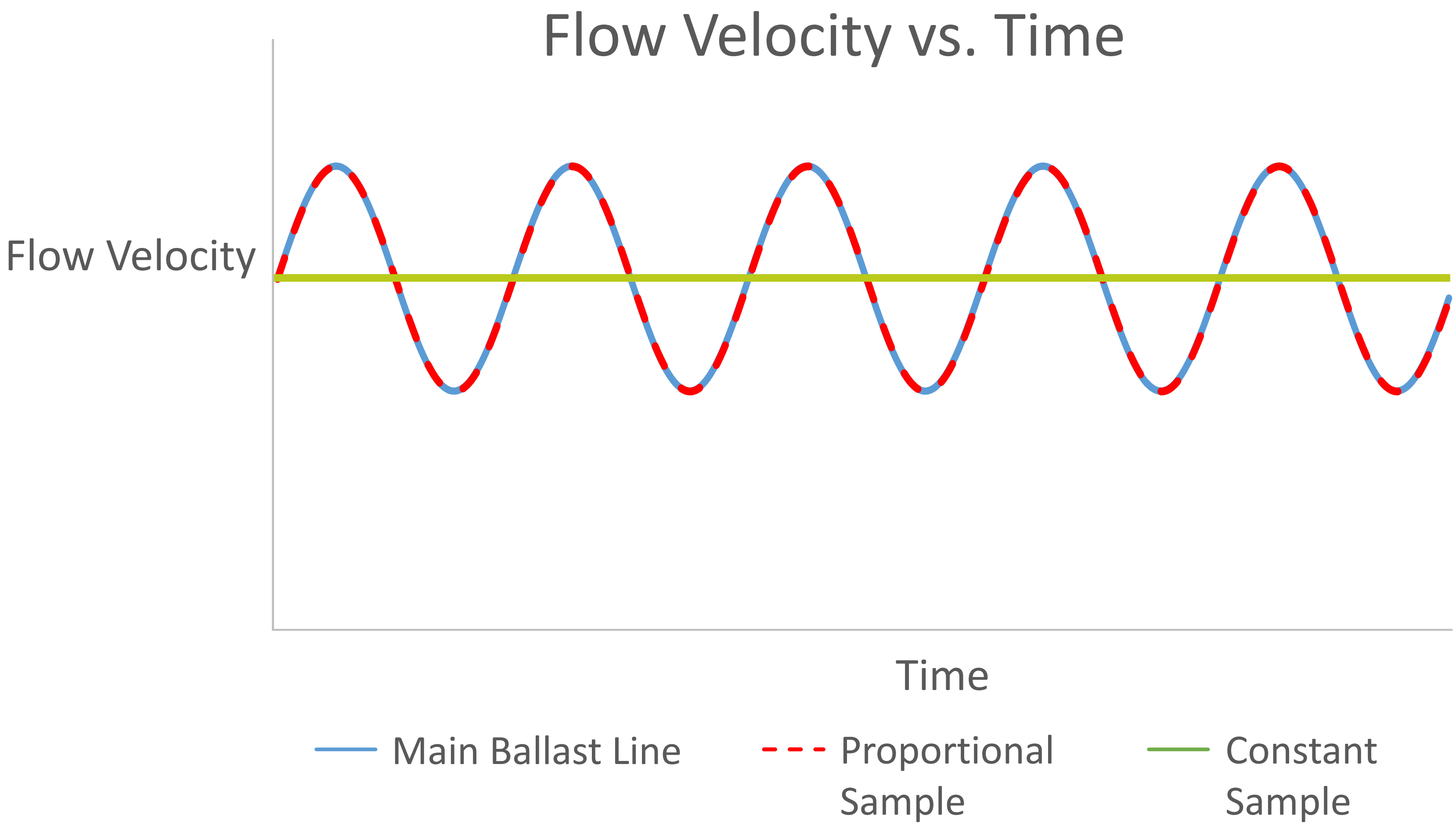
- Current guidance: sample probe should be sub-isokinetic; between 1.5 and 2.0 times the isokinetic diameter

OR

- Velocity entering the sample probe should be between 0.5 and 0.25 times the velocity in the main ballast line
  - Requires sample flow to be controlled proportionally to main ballast flow

Proportional Sample Flow Control

- Constant sample flow velocity vs. varying main ballast flow velocity
- Proportional sample flow velocity matching with main ballast flow velocity



Measuring Main Ballast Flow Rate

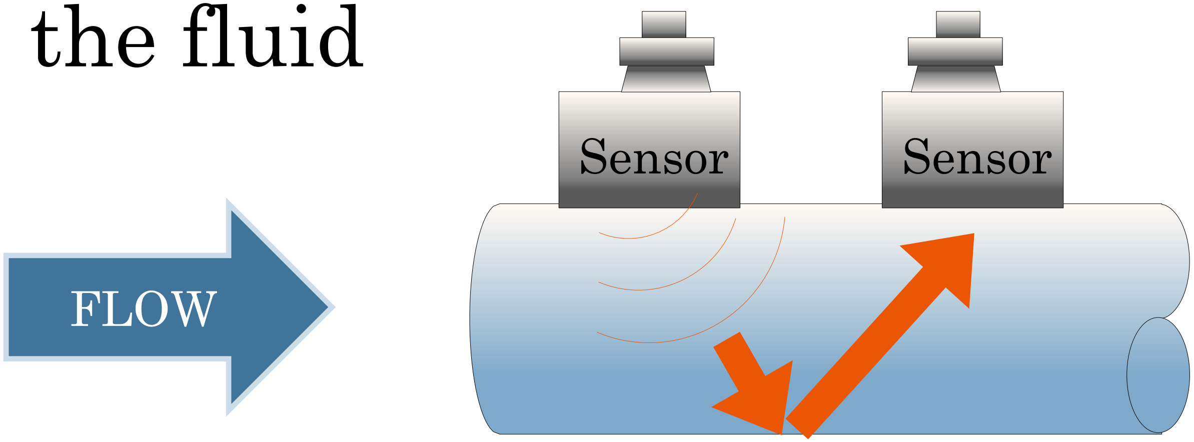
- Many ships do not have flow meters installed
  - Installation is not trivial (e.g., cutting or putting holes in ballast piping)

- External ultrasonic flow sensors, i.e., flow meters mounted on the exterior of the pipe, can be transported to a ship and are relatively easy to setup and remove

- Reliability needs to be validated

Measuring Main Ballast Flow Rate

- External ultrasonic flow sensor (transit-time)
  - Speed of sound is affected by the velocity of the fluid



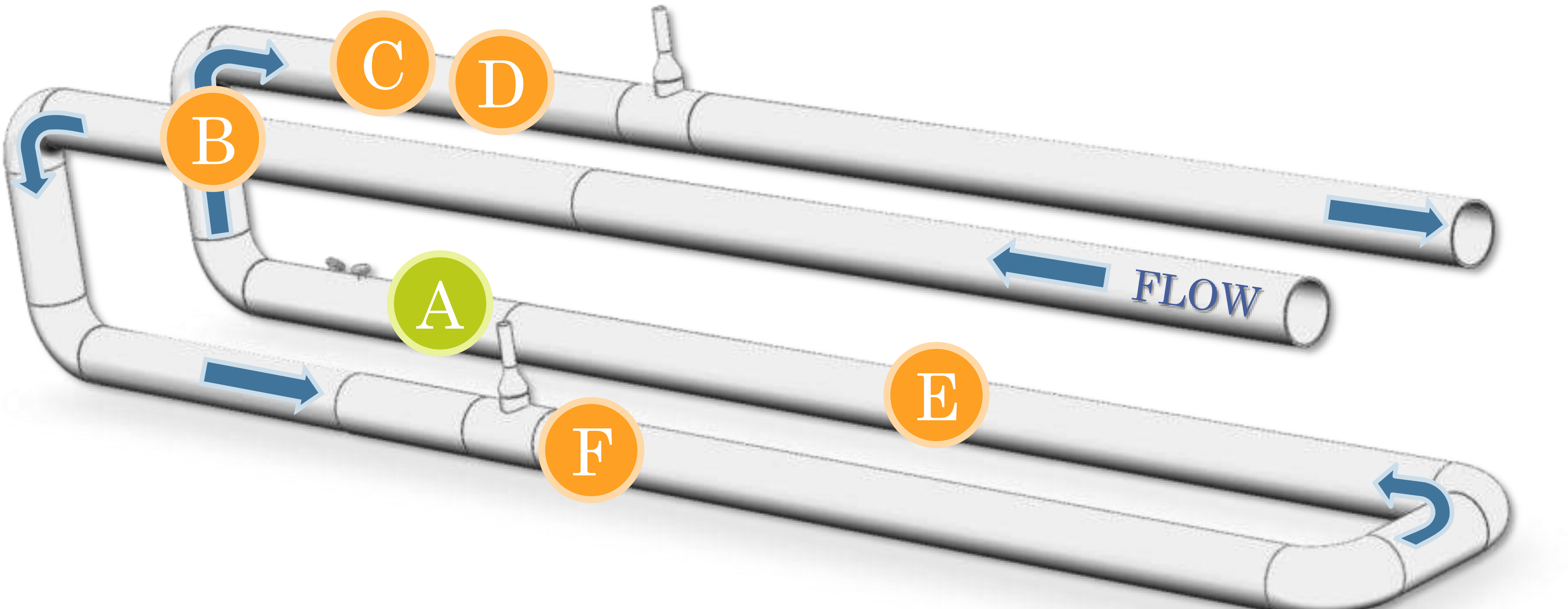
- Fluid must not contain high concentration of particles or bubbles

Experimental Goals

1 Determine the reliability of an external flow meter on a main ballast pipe

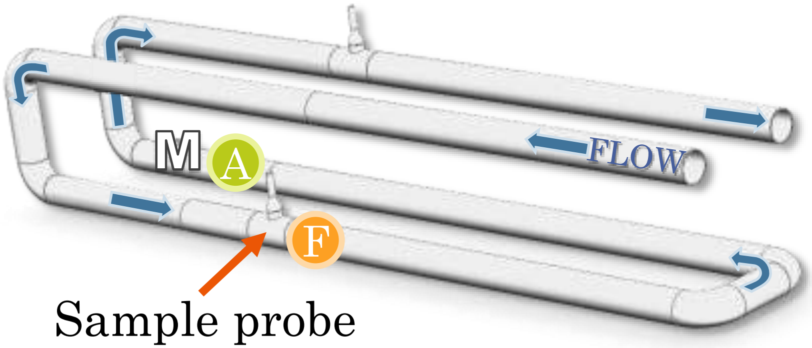
2 Evaluate the biological capture efficacy from sample flow controlled proportionally to main ballast flow

Ultrasonic Flow Sensor Testing



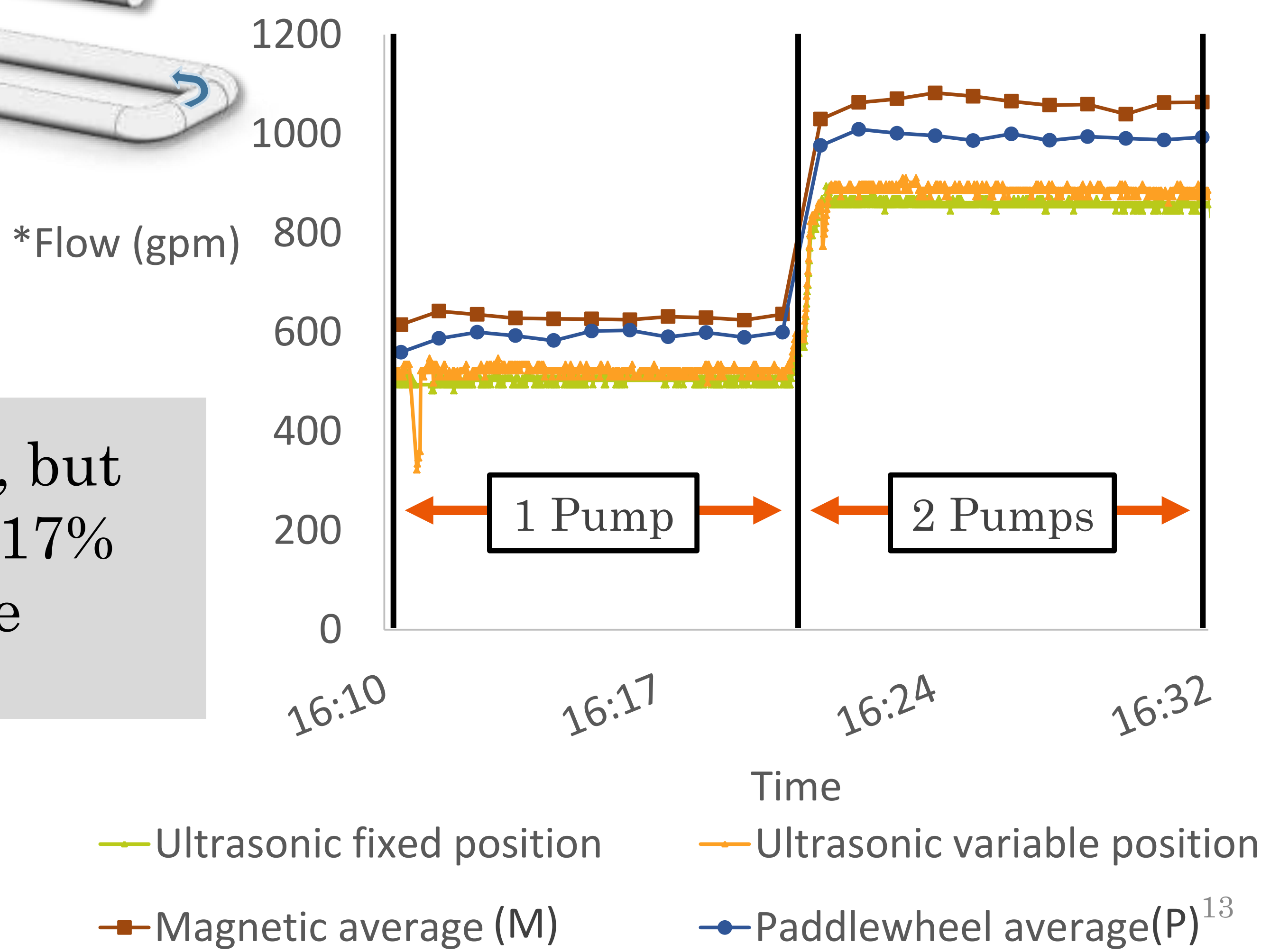
- One ultrasonic flow sensor installed at **fixed** location “A” per manufacturer’s instructions (long undisturbed pipe to ensure fully developed flow)
  - Also directly adjacent to in-line sensors
- The position of the other ultrasonic flow sensor **varied** along the piping loop at positions “B-F”

Ultrasonic Flow Sensor Testing Results



P	30 m upstream 10 m downstream

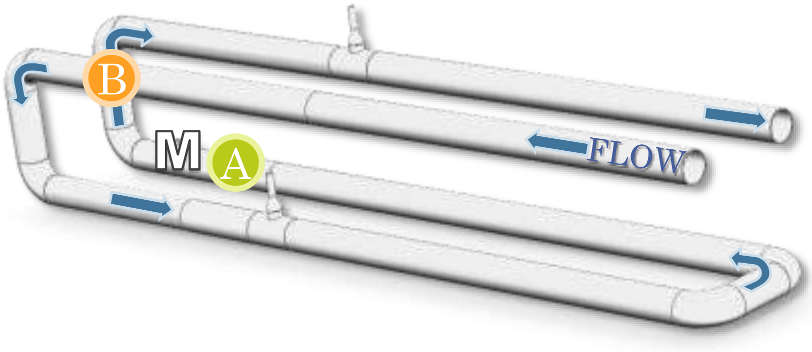
Position F: Directly downstream (< 1 pipe diameter) from sample probe



- Steady readings, but between 10 and 17% lower than inline sensors

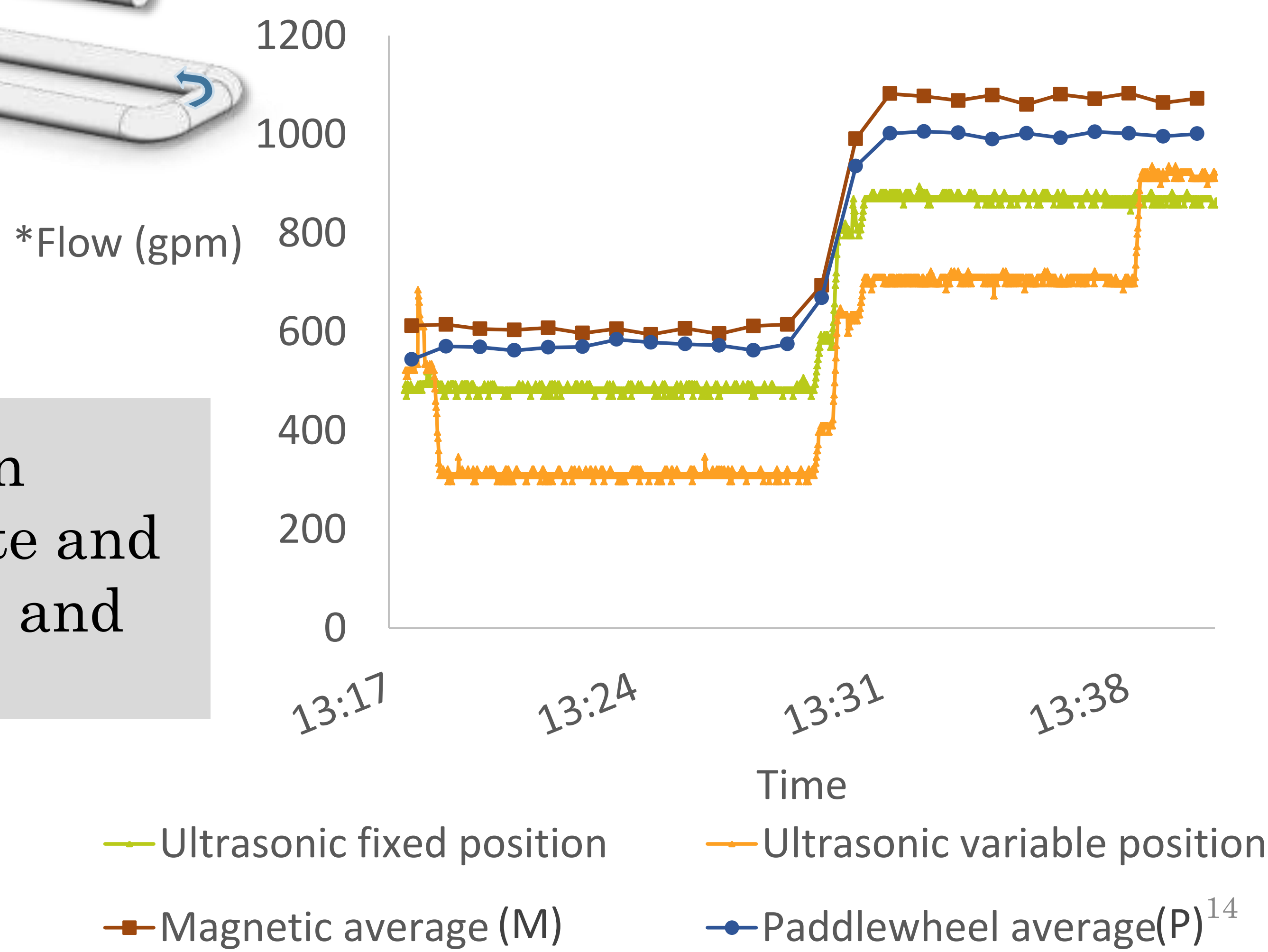
*1 gpm = 0.227 $m^3 h^{-1}$

Ultrasonic Flow Sensor Testing Results



P	30 m upstream 10 m downstream

Position B: 3 pipe diameters upstream of 90° elbow



- Variable position sensor inaccurate and spikes at ~13:18 and 13:38

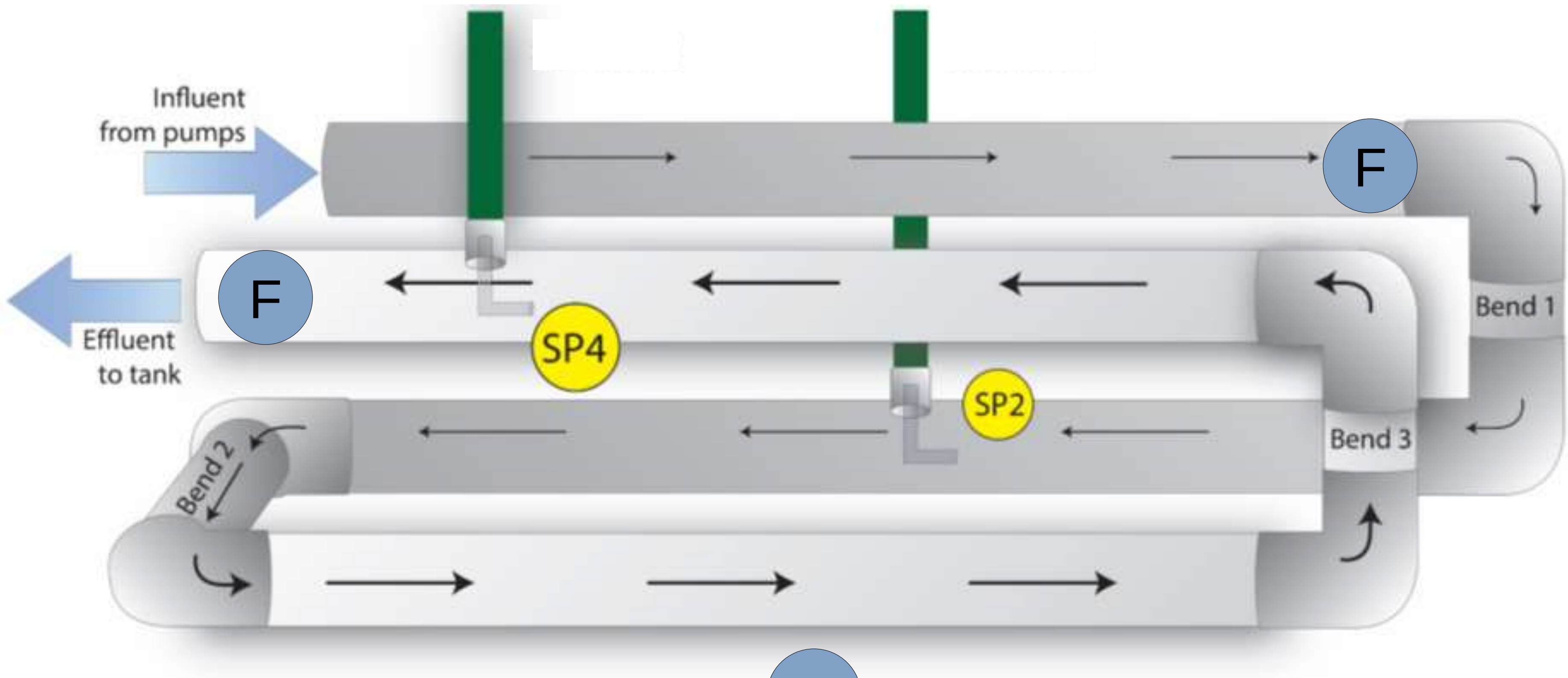
*1 gpm = 0.227 $m^3 h^{-1}$

Biological Validation Experiments

- Two sampling devices operated simultaneously:
  - One set to sample at a constant flow rate through entire ballast operation
  - The other continuously and automatically adjusted the sample flow rate proportional to the main ballast flow rate (measured using ultrasonic flow sensors)
- 4 test cycles
  - Biological data for organisms ≥50 µm were compared between samples collected using each device

Biological Validation Experiments

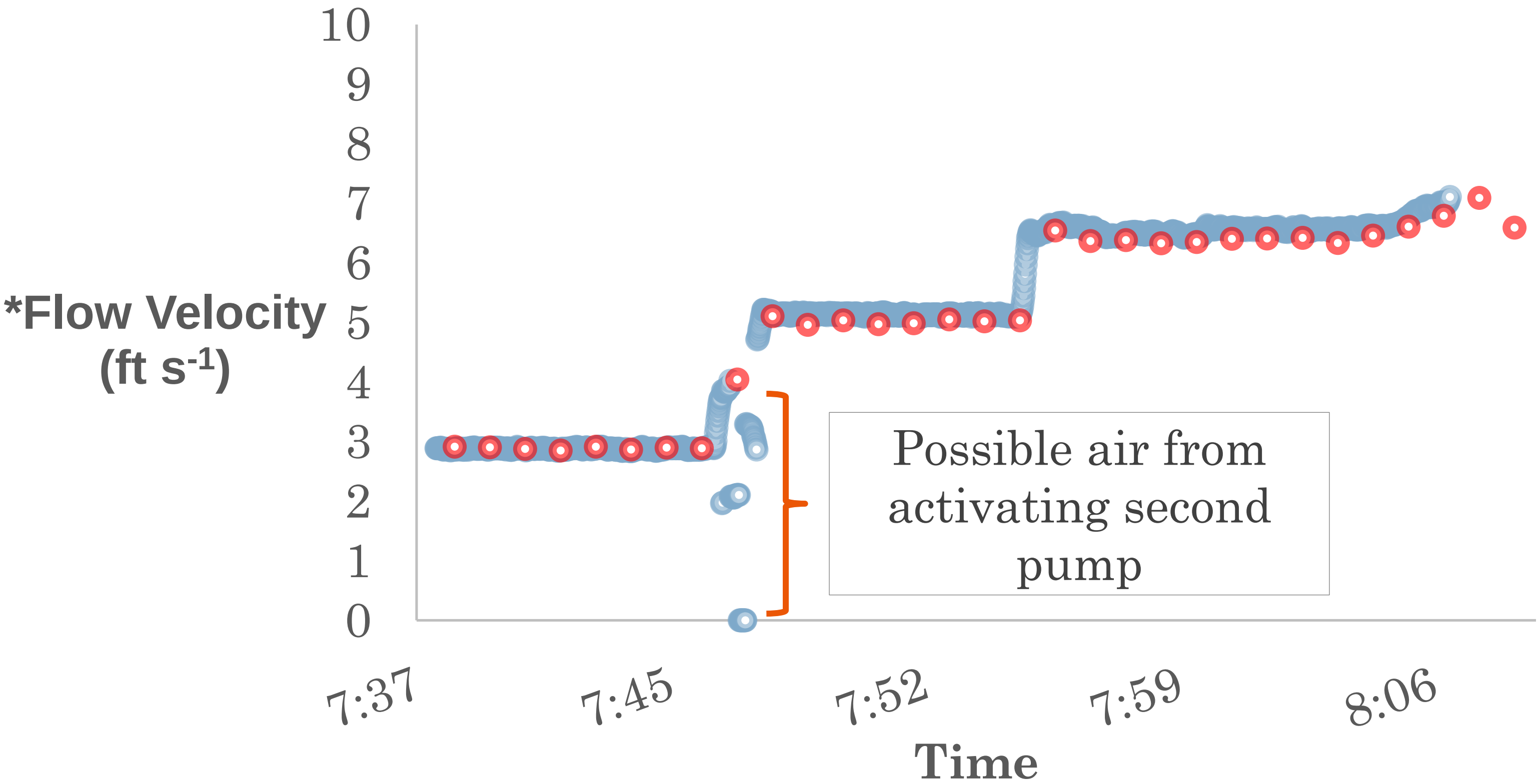
- 3 m^3 sample volumes collected using proportional and constant flow rates



F External Ultrasonic Flow Sensor

SP Inline sample port

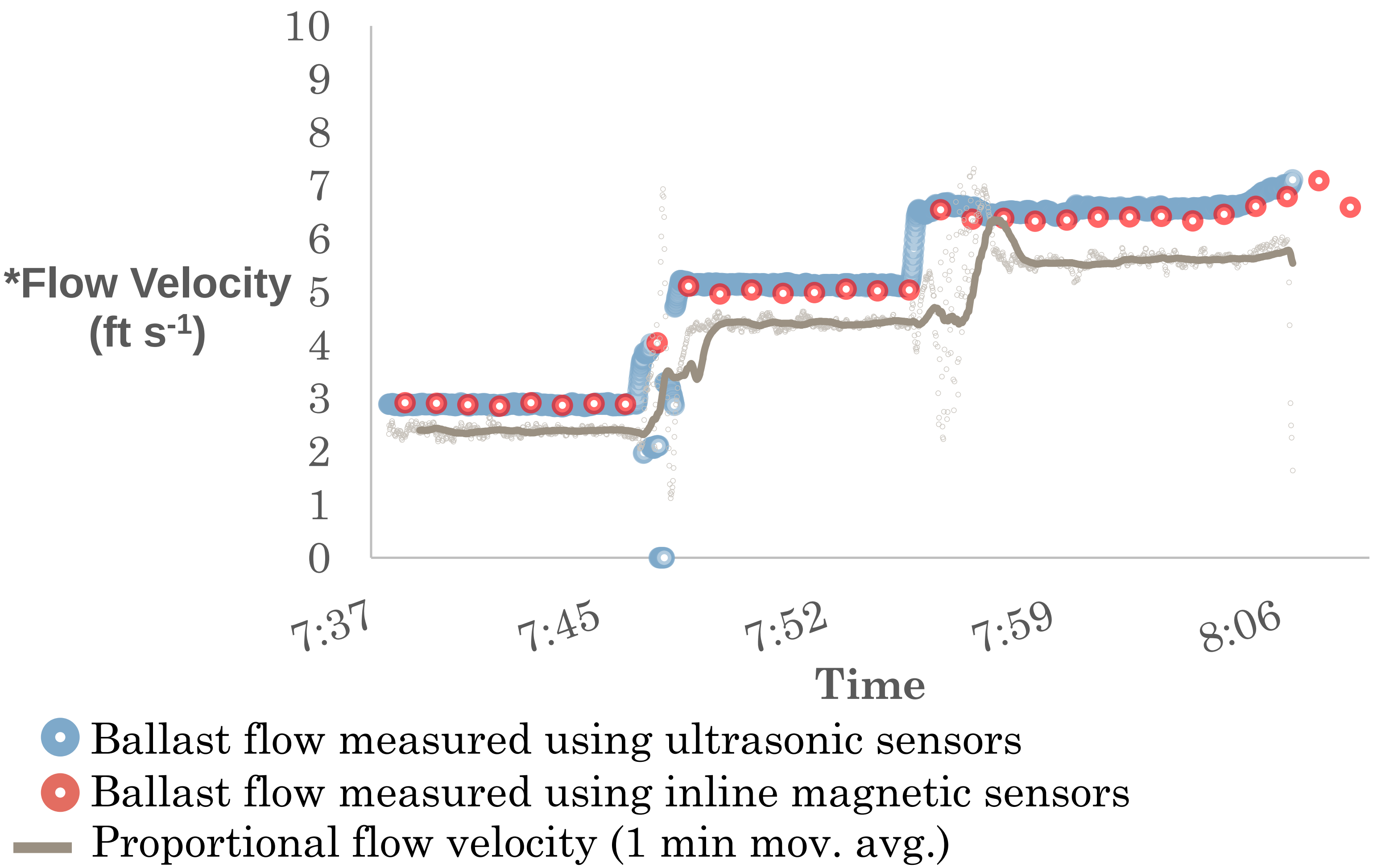
Biological Validation Experiments



Ballast flow measured using ultrasonic sensors
Ballast flow measured using inline magnetic sensors

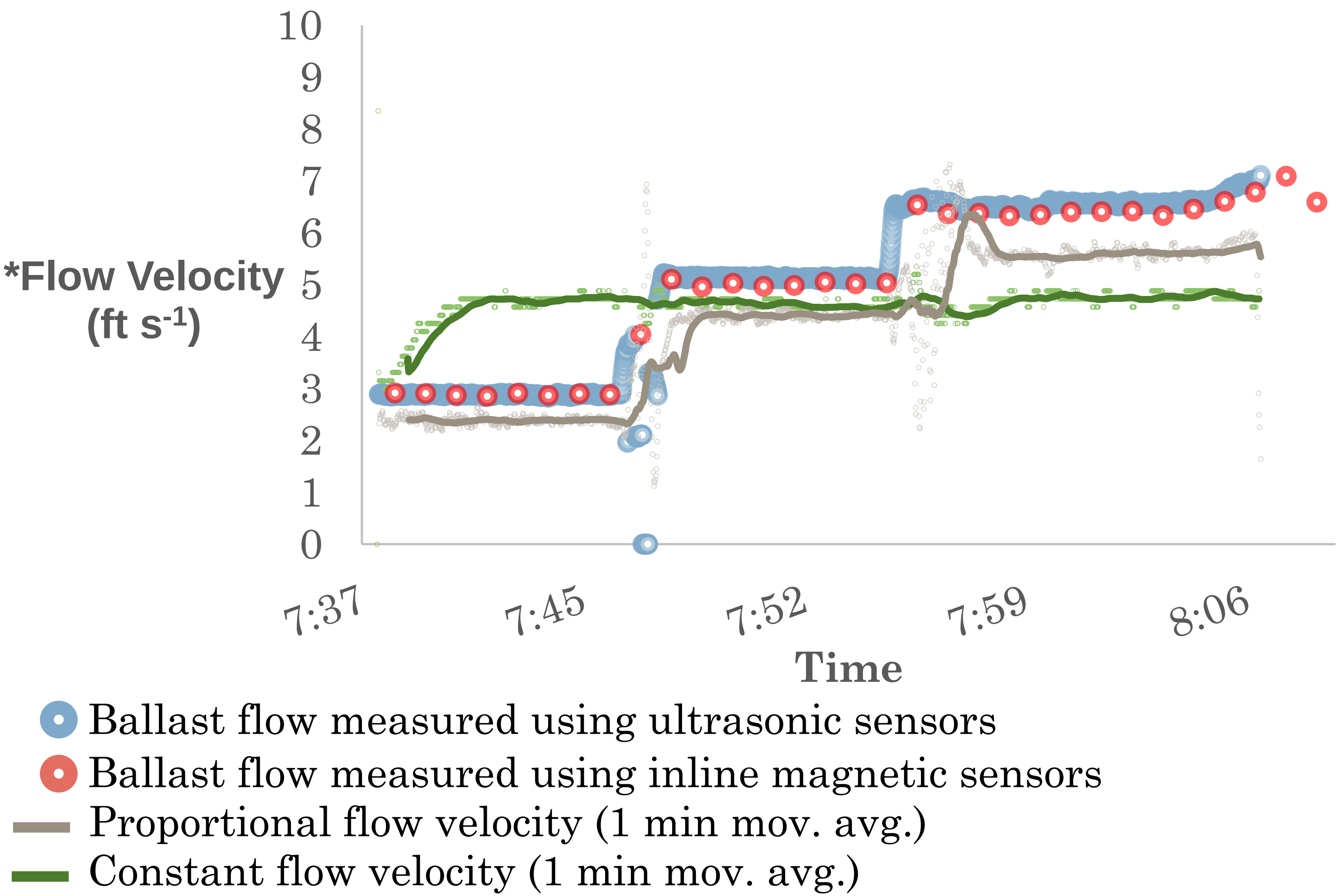
*1 ft s^{-1} = 0.3048 m h^{-1}

Biological Validation Experiments



*1 ft s^{-1} = 0.3048 m h^{-1}

Biological Validation Experiments



*1 ft s^{-1} = 0.3048 m h^{-1}

Conclusions on Ultrasonic Sensors

- Measurement accuracy and stability was best when the sensor was set up per the manufacturer's specifications, but still performed adequately otherwise
- Factory calibrated sensors consistently measured lower flow values than in-line magnetic flow meters or paddle wheels
- Very sensitive to air in the pipe
- Had to be installed in a full, non-flowing pipe
- Errors occurred when installed directly next to each other or along straight section of pipe
  - Possible acoustic signal interference

Conclusions on Biological Validation

- No significant difference in living organism concentrations between proportional and constant sample flow
  - Proportional sampling still required to achieve representative sample

Conclusions Overall

- To achieve representative sampling on a ship, external ultrasonic flow sensors could possibly provide a workable solution for proportional flow control where in-line flow meters are unavailable
  - Depends heavily on air in the ballast lines

Acknowledgements

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References

US Coast Guard (2012) Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters (Final Rule). Federal Register 77:17254-17304

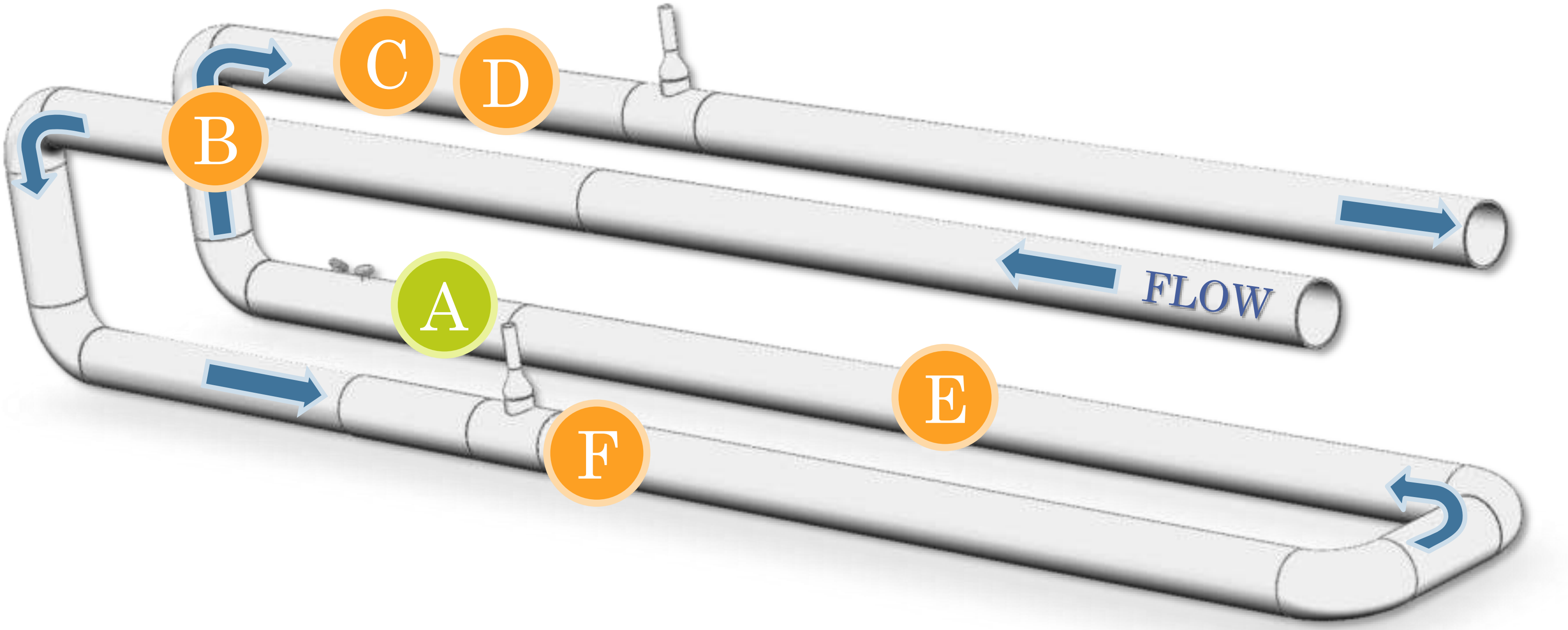
US Environmental Protection Agency (2010) Generic protocol for the verification of ballast water treatment technology, version 5.1. Report number EPA/600/R-10/146, United States Environmental Protection Agency Environmental Technology Verification Program, Washington, DC http://www.uscg.mil/hq/cg5/cg522/cg5224/docs/600r10146.pdf

Supplemental Slides

Ballast Water Discharge Standards

Organization and standard	Living organisms ≥50 µm in minimum dimension[A]	Living organisms ≥10 µm and <50 µm in minimum dimension[B]	Toxigenic Vibrio Cholerae[C]	Escherichia Coli	Intestinal Enterococci
US Discharge Standard	$<10\ m^{-3}$	$<10\ mL^{-1}$	<1 cfu $100\ mL^{-1}$	<250 cfu $100\ mL^{-1}$	<100 cfu $100\ mL^{-1}$
IMO Regulation D-2 Ballast Water Performance Standard	$<10\ m^{-3}$	$<10\ mL^{-1}$	<1 cfu $100\ mL^{-1}$ or <1 cfu g^{-1} (wet weight zoopl.)	<250 cfu $100\ mL^{-1}$	<100 cfu $100\ mL^{-1}$

[A]Nominally zooplankton. [B]Nominally protists. [C]Serotypes O1 and O139. cfu = colony forming unit, IMO = International Maritime Organization, US = United States, and zoopl.= zooplankton.



Location USFM 1	Location 1 (Fixed) Distance from anomaly	Location USFM 2	Location 2 (Variable) Distance from anomaly	Posiiton Notes
A	~23D- (186")	A	168.5	Both flow meters located next to each other
A	~23D- (186")	B	3D+	Difficulty getting signal, had to prime pipe
A	~23D- (186")	C	3D-	
A	~23D- (186")	D	5D-	
A	~23D- (186")	E	~11D- (86")	bottom of pipe
A	~23D- (186")	F	~1D-	directly downstream of sample port (~12D- from elbow)

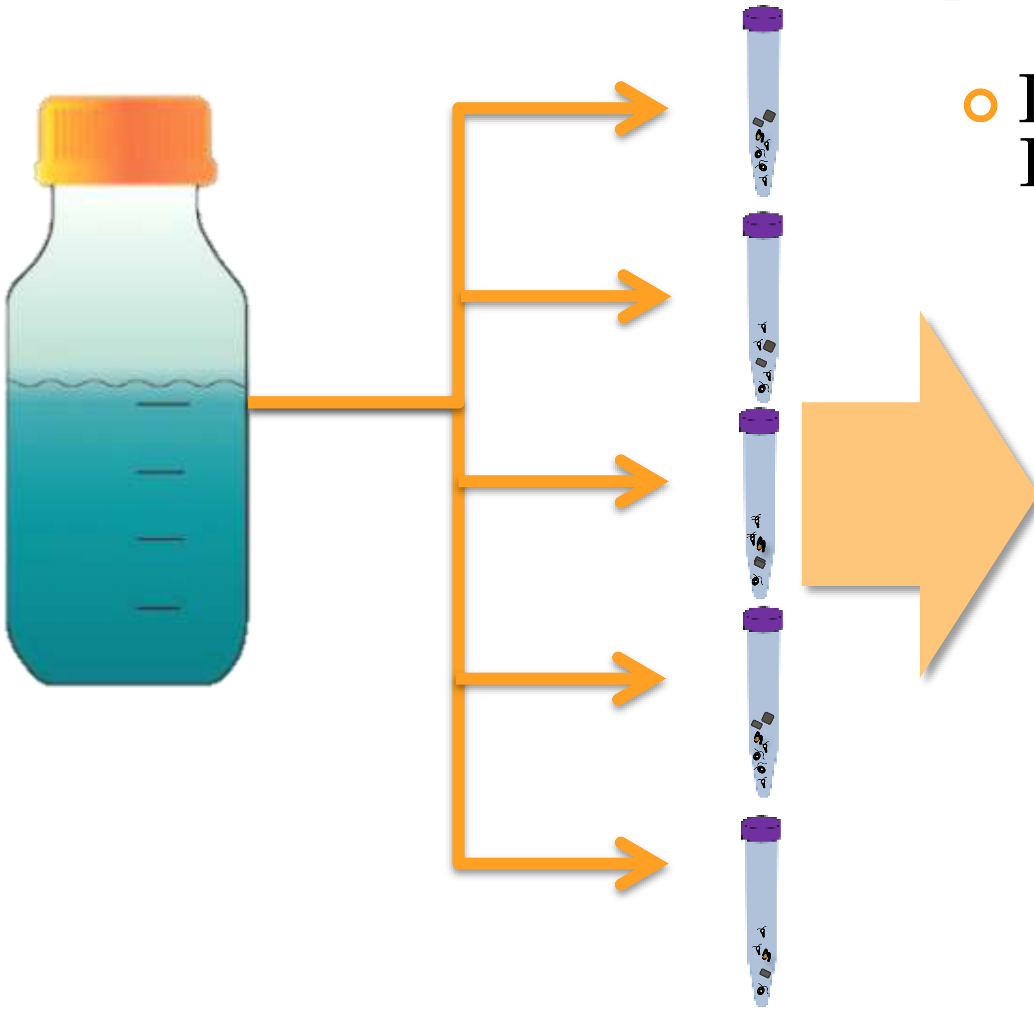
Biological Validation Experiments

- Concentrated sample collected from constant and proportional flows are rinsed into separate flasks

- Samples are transport to the biology laboratory for analysis

Biological Validation Experiments

- Each ≥50 µm sample was mixed, subsampled, and diluted for a total of 5 subsamples for each skid



- Live/Dead Counts using Bogorov Chambers

External Flow Meter Selection

- Transit-time flow meter chosen, since Doppler flow meters are restricted to fluids containing particulates
- Siemens SITRANS FUP1010
  - **Pipe sizes** between Diameter Nominal (DN) 6 to DN 9140 **(0.25" to 360")**
  - **Accuracy** ±0.5 to 2.0%
  - **4-20 milliamp (mA)** output
  - **Weatherproof**
  - **Portable** and **battery- powered**
  - ~$9000

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