Measurement Standard of Air Speed and its Calibration Service Networks in Korea

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KRISS Fluid Flow

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Air Speed measurement in Korea

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3. KMA (Korea Meteorology Agency)

Air Speed in KRISS: Making air speed standard system

- On 1987, Korea had no national standard for Air Speed
- On 1988, 88' Seoul Olympic Game
  - Design and surveying the air speed standard system in the world
  - Check the wind tunnel in Korea: KMA and Universities
  - Check the wind tunnel in other NMIs: NBS, NRLM, PTB and NEL…

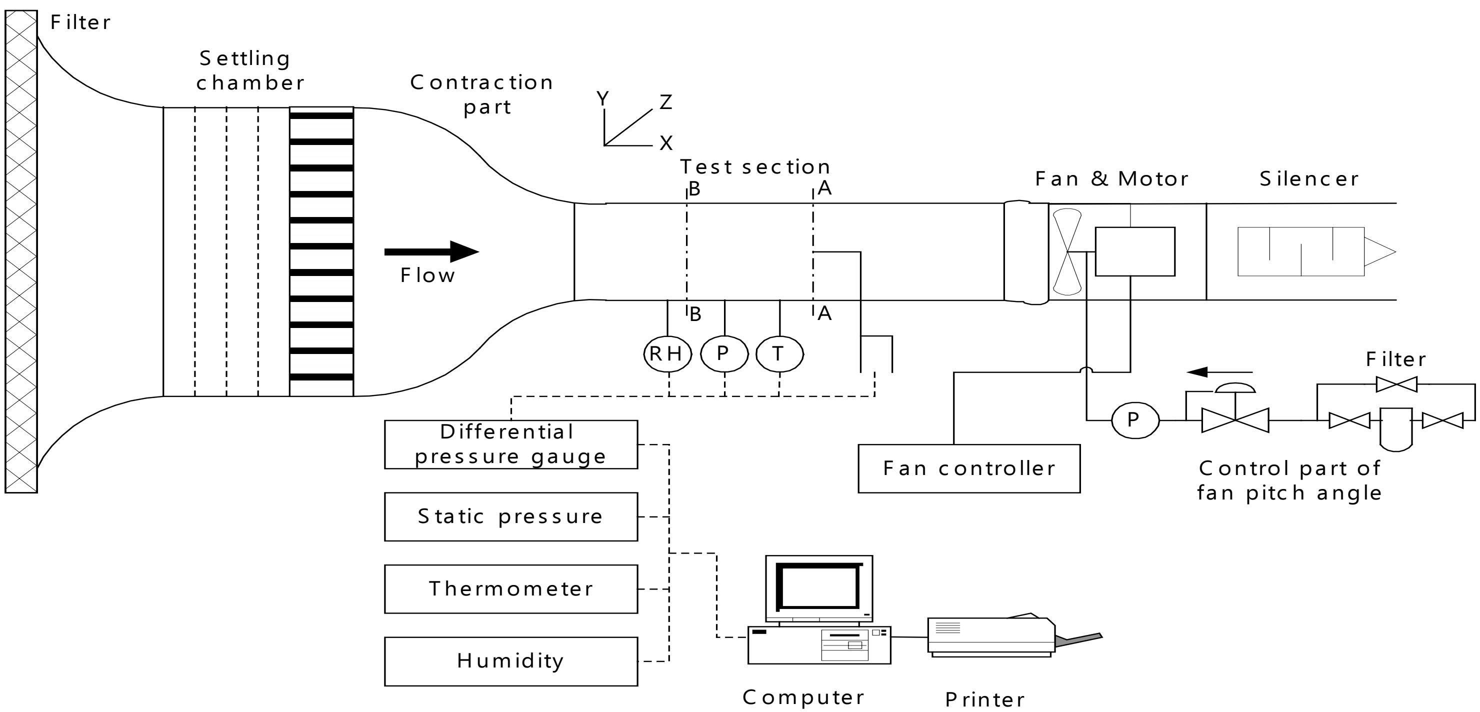
ⓒPhoto by Bohuncheo

Air Speed in KRISS: Making

- On 1989, Select the design of wind tunnel of NBS and TSI LDA
- On 1991, Installation of Wind Tunnel and LDA in KRISS
- **VVVF with pitch control**

Air Speed in KRISS: Making

- On 1989, Select the design of wind tunnel of NBS and TSI LDA
- On 1991, Installation of Wind Tunnel and LDA in KRISS
- **Test section size: 900 mm x 900 mm**



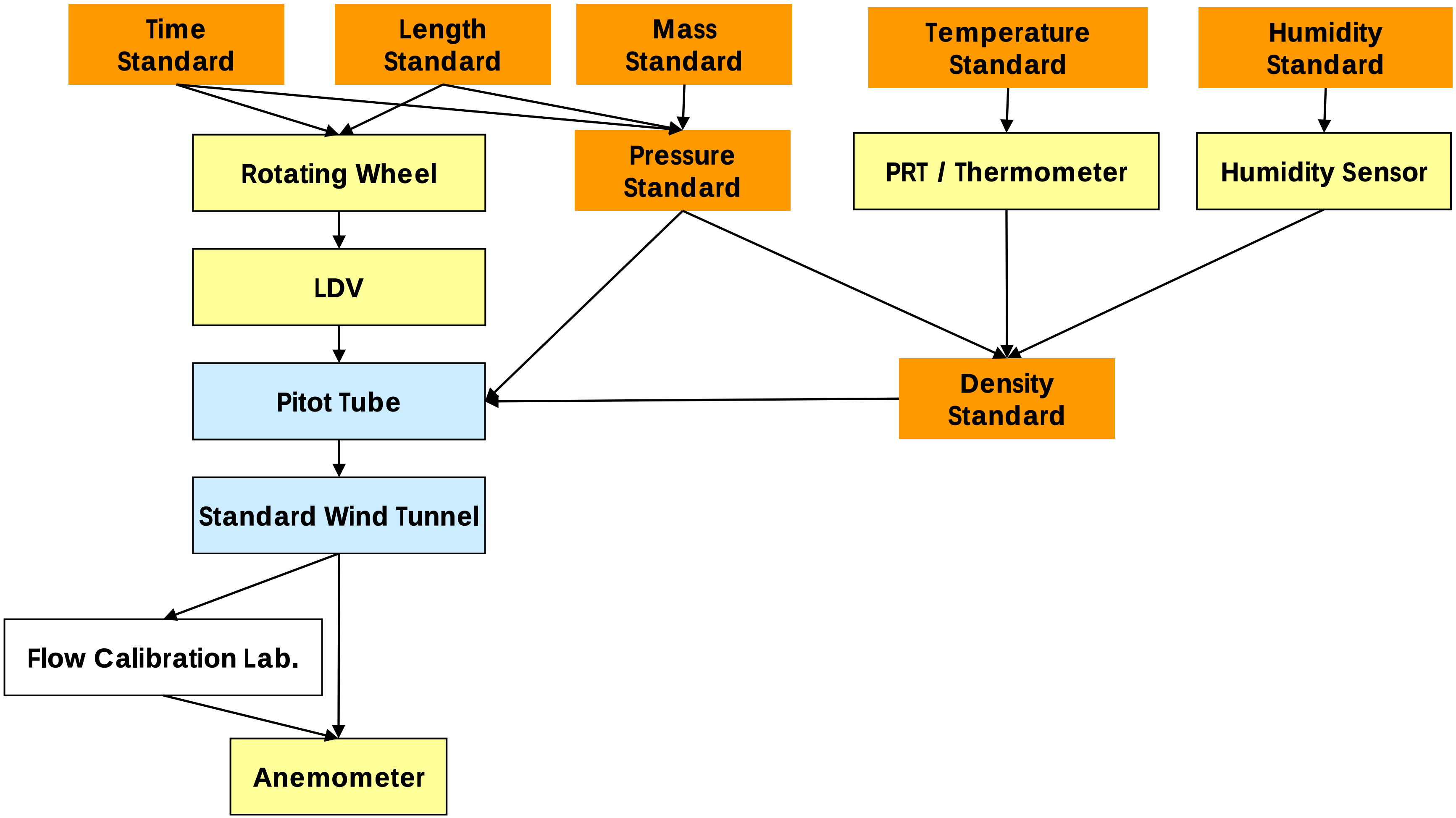
Air Speed in KRISS: Making

- On 1989, Select the design of wind tunnel of NBS and TSI LDA
- On 1991, Installation of Wind Tunnel and LDA in KRISS
- **Uncertainty with Pitot tube: 1 % below 5 m/s, 0.6 % above 5 m/s**

Equipments	Manufacturer & Model	Q'ty	Specification	Remark
Wind tunnel body	Seo Won Machinery Co.	1	2 m/s to 16 m/s	
Fan and controller	ABB	1	45 kW VVVF and Pitch control	
Pitot tube	Airflow	1	NPL type	
Differential pressure gauges	MKS S/N 95236154A S/N 95223254A	2	0-20 Pa, 0-200 Pa	
Pressure gauge	Paroscientific S/N 76772	1	0-100 kPa Portable standard	
Thermometer	Labfacility S/N T842	1	2-ch. 100 Ω PRT discrimination : 0.01 °C	
Humidity gauge	E+E EE31 S/N 0502/P25262.0005	1	0-100 % RH 10-30 °C	

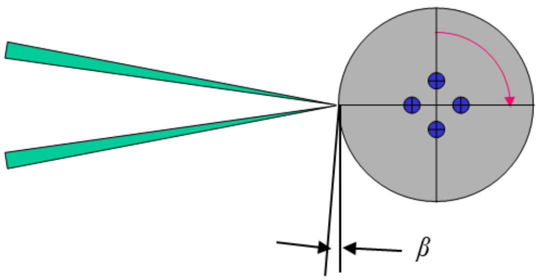
Air Speed in KRISS: Primary of air speed standard

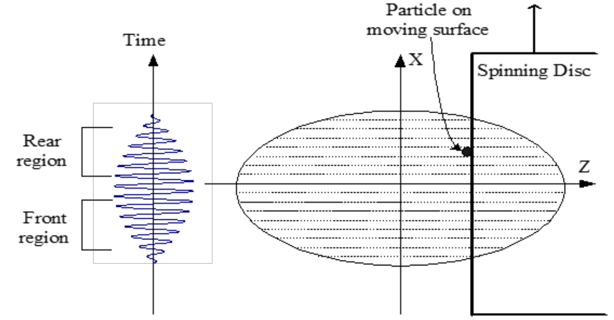
- Air Speed traceability to the national standard



Air Speed in KRISS: Primary

- **LDA Calibration by Rotating Wheel**

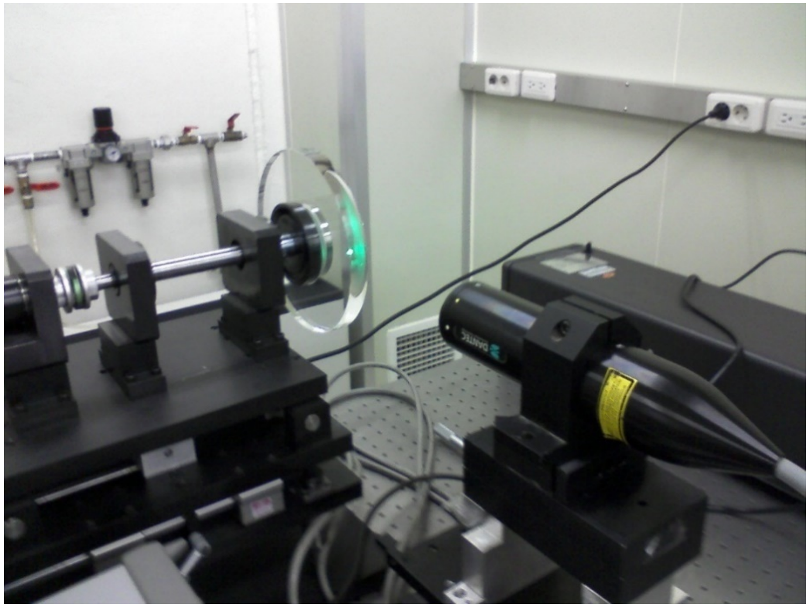




$V_{ldv} = d_f \times f_D$ ⇔ $V_{disc} = r \times \omega \times \cos\beta$ → Obtain local fringe spacing

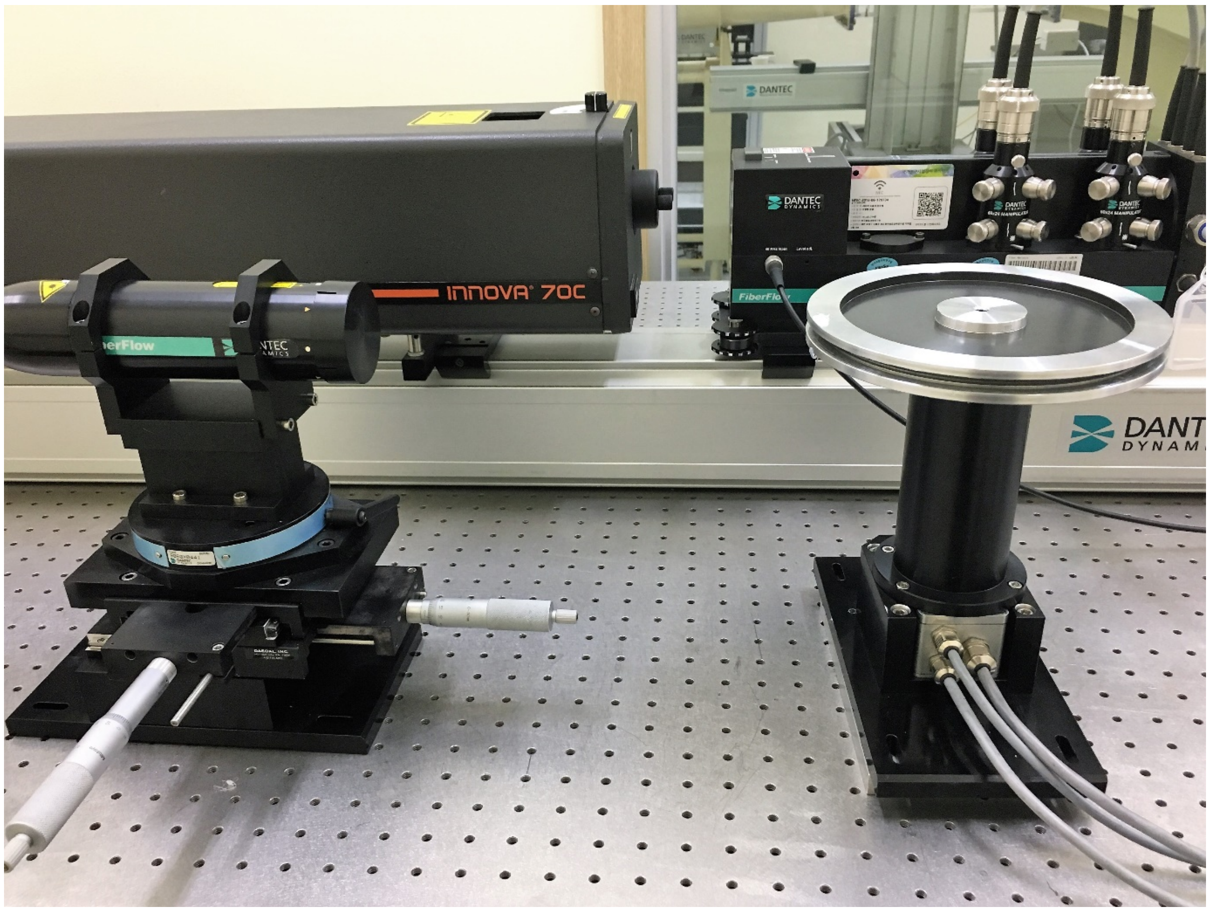
→ $d_f = r \times \omega / f_D \times \cos\beta$ β <1 degree

ⓒYang, C.T. of CMS



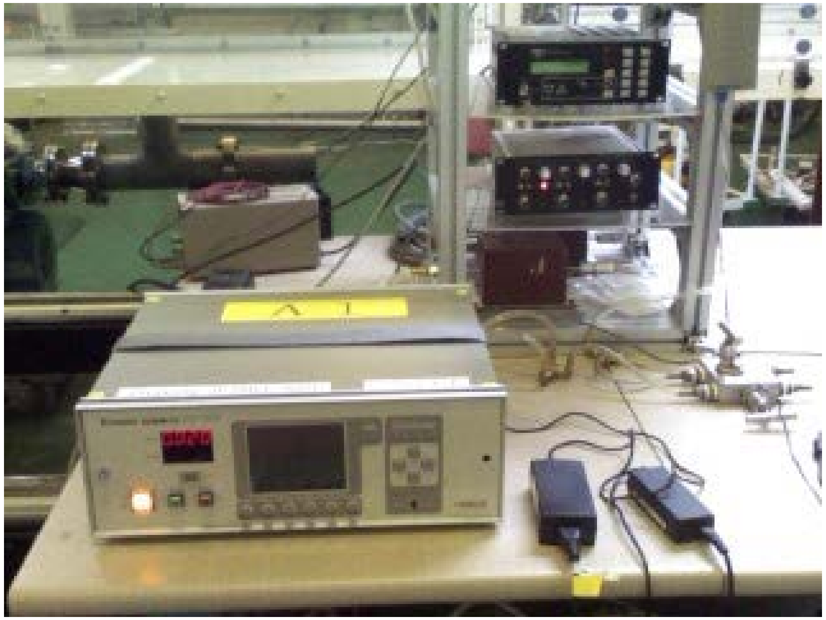
Air Speed in KRISS: Primary

- **On 2015, Replaced the LDA by DANTEC and modified the arrangement of rotating disc from horizontal to vertical**



Air Speed in KRISS: Key Comparison for MRA (Mutual Recognition Agreement)

- APMP KC TCFF.FF-K3-2009: Air speed KC in APMP, Pilot Lab was NMIJ
- Participated country: 6
- Transfer standard: Ultrasonic anemometer of Sonic Co.
- Test air speed: 2 m/s – 20 m/s



Air Speed in KRISS: KC

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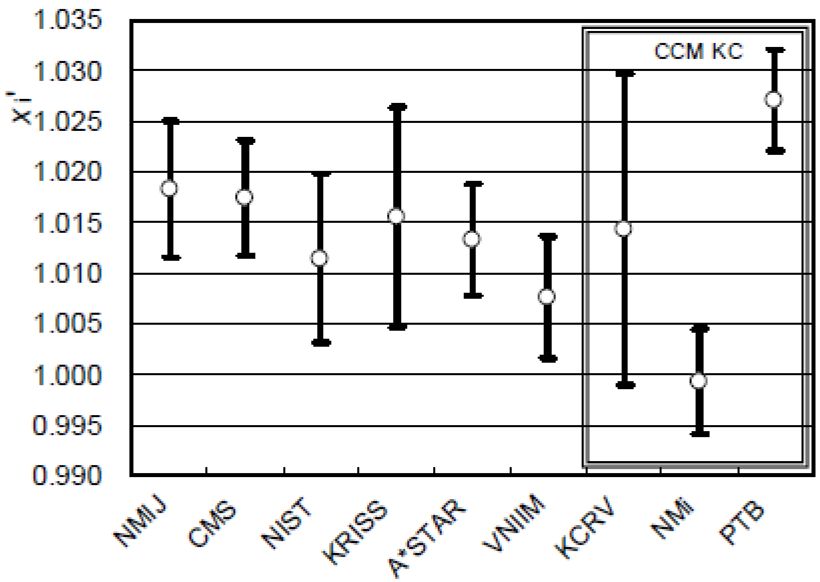

Fig. 3 Corrected calibration results at 2 m/s. Values of KCRV, NMi and PTB are taken from Final report of CCM KC.

Air Speed in KRISS: KC

- APMP KC TCFF.FF-K3-2009: Air speed KC in APMP, Pilot is NMIJ
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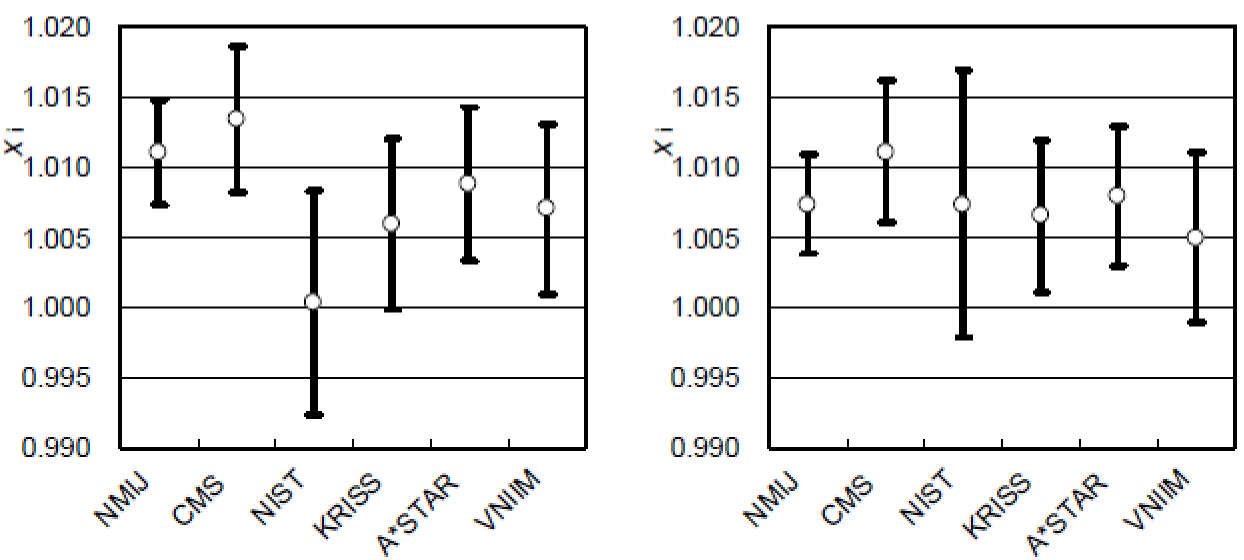


Fig. 4 Calibration results at 5 m/s. Fig. 5 Calibration results at 10 m/s.

Air Speed in KRISS: KC

- APMP KC TCFF.FF-K3-2009: Air speed KC in APMP, Pilot is NMIJ
- Participated country: 6
- Transfer standard: Ultrasonic anemometer of Sonic Co.
- Test air speed: 2 m/s – 20 m/s

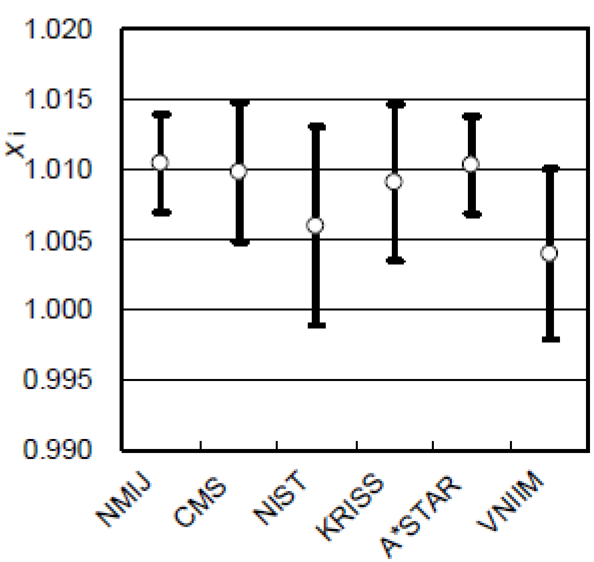


Fig. 6 Calibration results at 16 m/s.

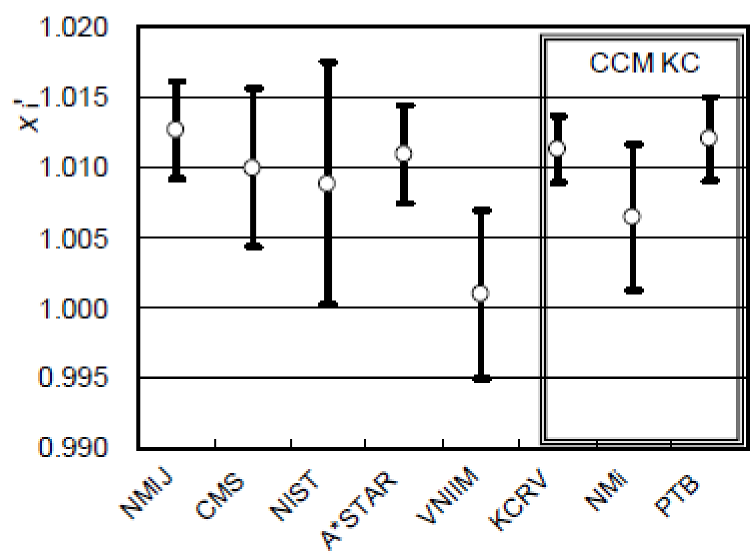
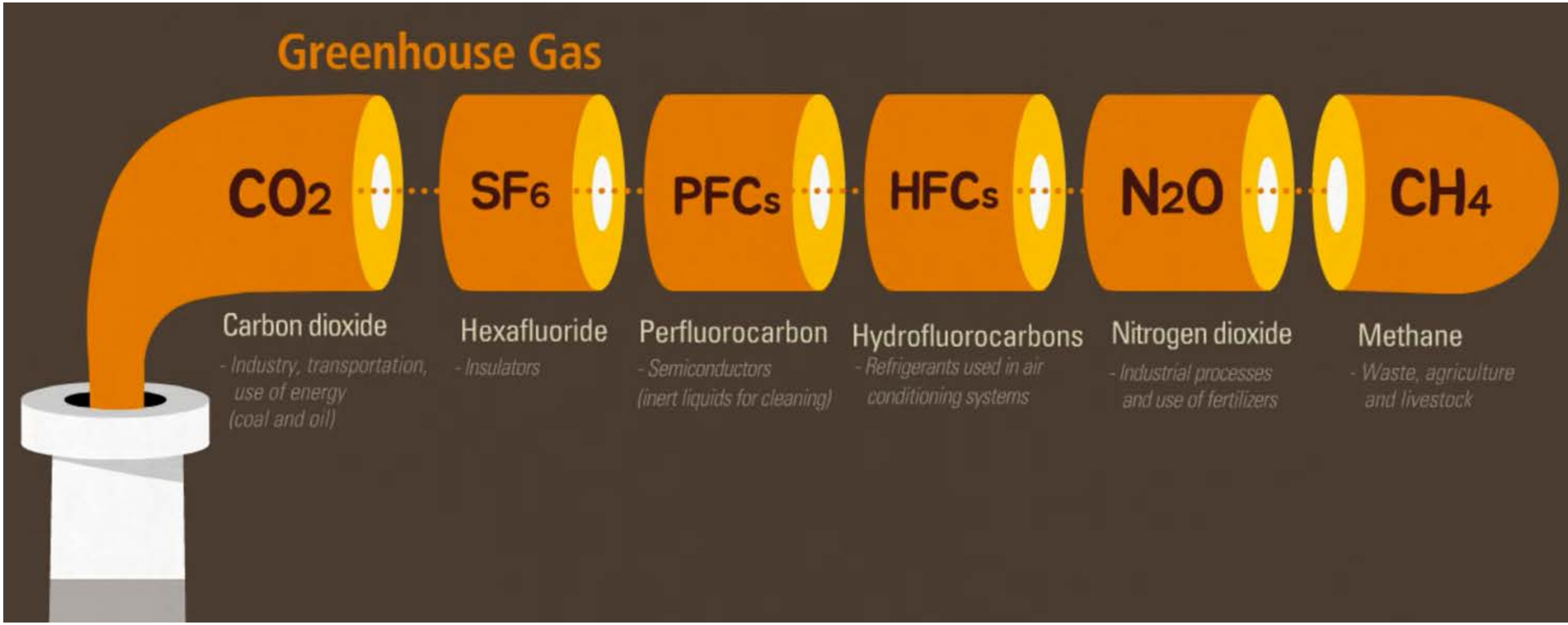


Fig. 7 Corrected calibration results at 20 m/s. Values of KCRV, NMi and PTB are taken from Final report of CCM KC.

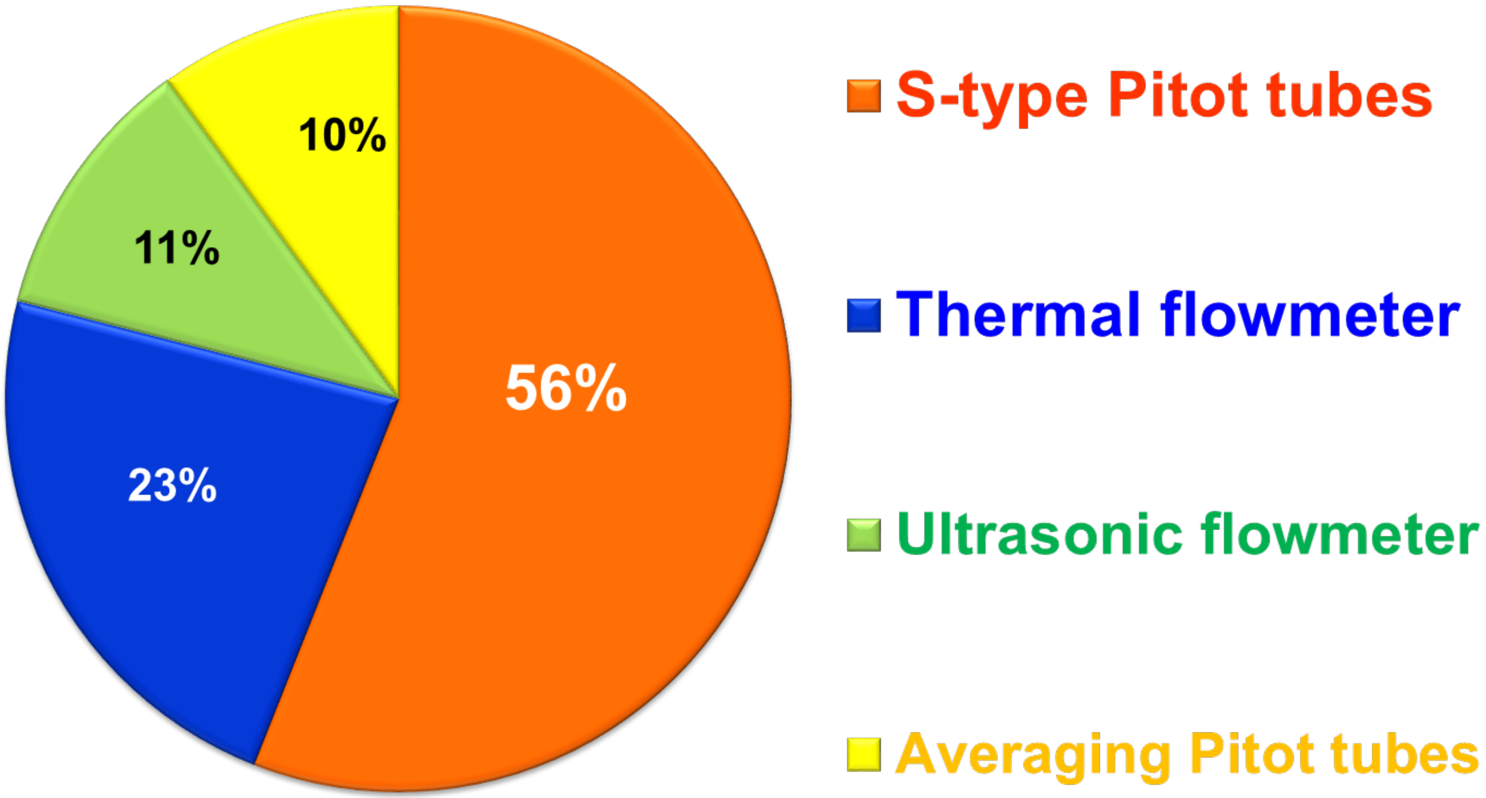
Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Background**
  - **Almost 90% of greenhouse gas emission comes from the energy and industrial fields such as heavy industry/ petrochemical / semiconductor and power plant**



Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

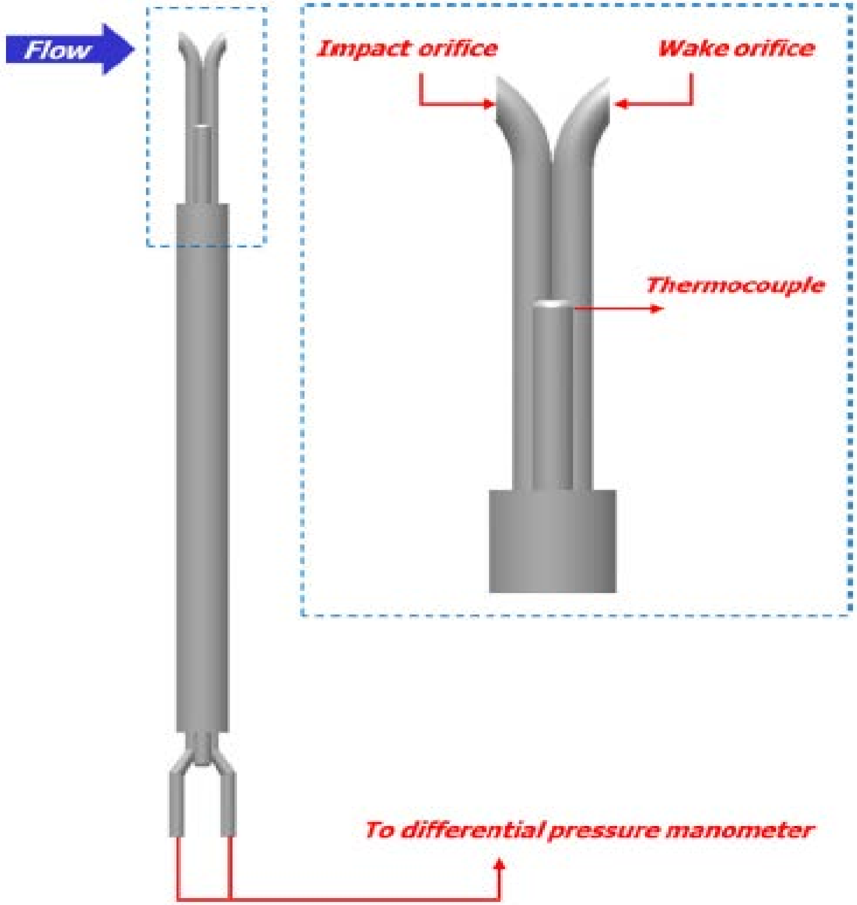
- **Background:** Type of anemometers in Stack of Korea



Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Background:** S-type Pitot Tube

- Large pressure orifices(Φ=5~10mm) & Strong tubes for high dust environments like industry stack (ISO 10780, KS M9429, EPA method2)
- Measurement differential pressure between an impact(total pressure) and wake orifice(static pressure) based on Bernoulli equation



$$V = C_{P,S}\sqrt{\frac{2\Delta P}{\rho}}$$

V : flow velocity in the stack gas(m/s)

$C_{P,S}$: S type Pitot tube coefficient

ΔP : differential pressure between impact and wake orifice (Pa)

ρ : density of the stack gas (kg/m^3)

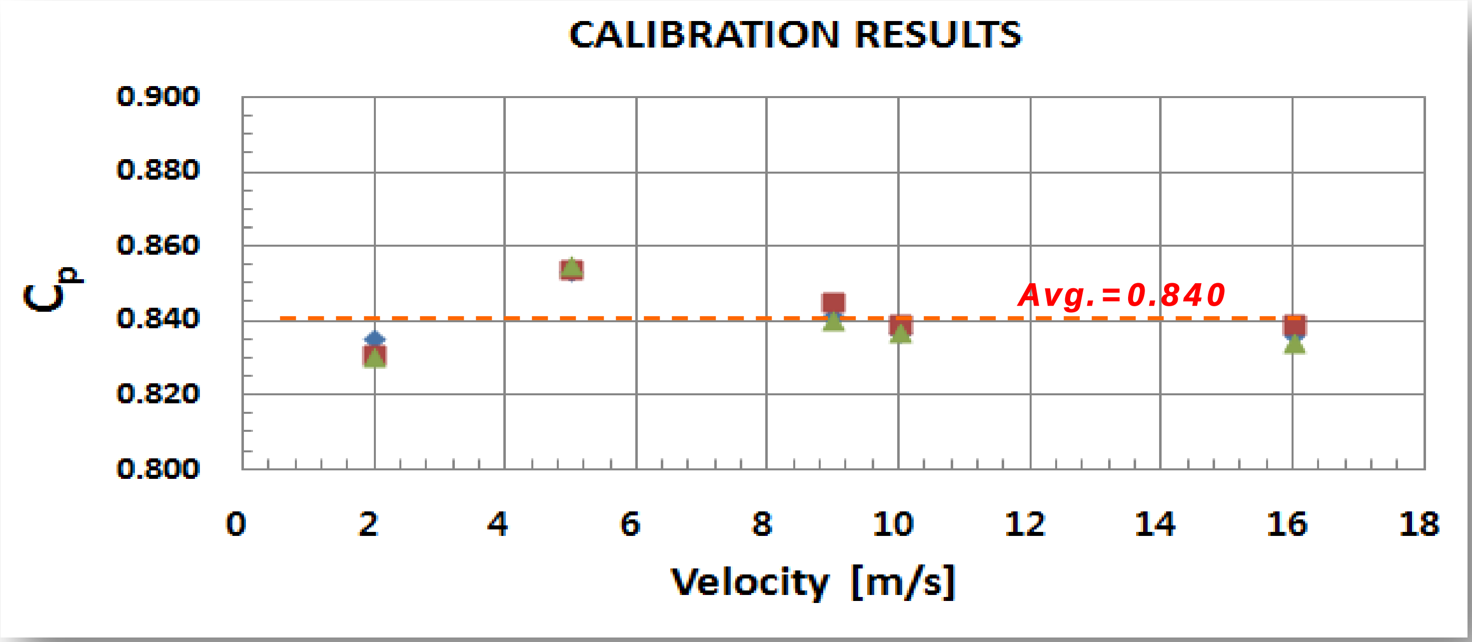
Background: Calibration of S-type Pitot Tube

- Determination by comparing the differential pressure of standard pitot tube and S-type Pitot tube

$$C_{P,S\cdot type} = C_{P,Std}\left(\frac{\Delta P_{Std}}{\Delta P_{S\cdot type}}\right)$$

$C_{p,s\text{-}type}$: S-type Pitot tube coefficient
$C_{p,std}$: Standard Pitot tube coefficient

$\Delta P_{s\text{-}type}$: differential pressure of S-type Pitot tube
ΔP_{std}: differential pressure of Standard tube



Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Background: On site measurement by S-type Pitot Tube**

Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Background:** S-type Pitot tube is usually installed and inserted in harsh environment such as tall stack height and high gas temperature

Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Background: Difficult to observe the inside of the stack and verify the precise installation of the S-type Pitot tube**

Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

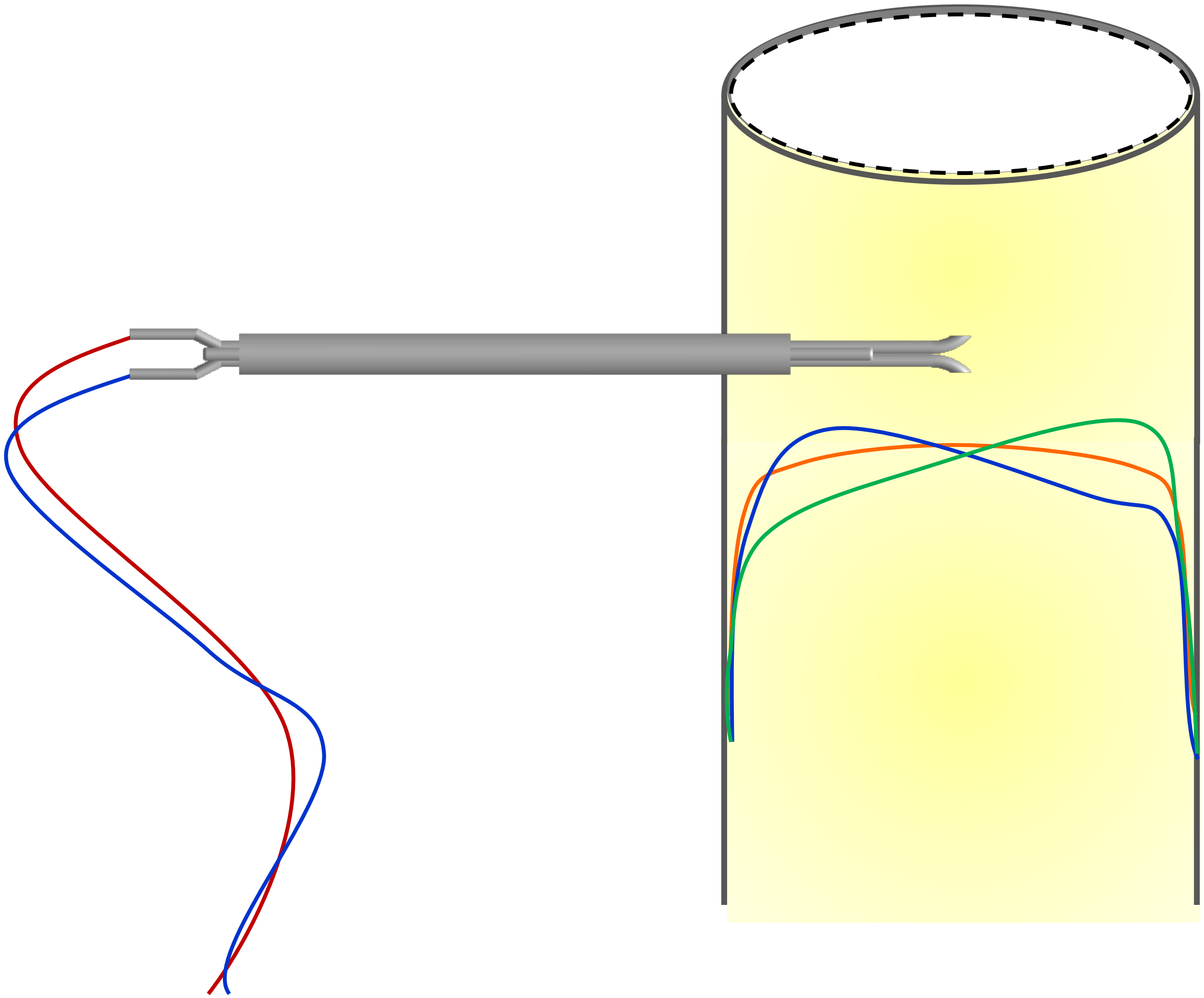
Pride KRISS Since 1975

- **Background:** **What Happen in the Stack?**

Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Background: What happen in the Stack?**

- Flow velocity of emission gas can be altered due to the unstable process in particular industrial condition of plant



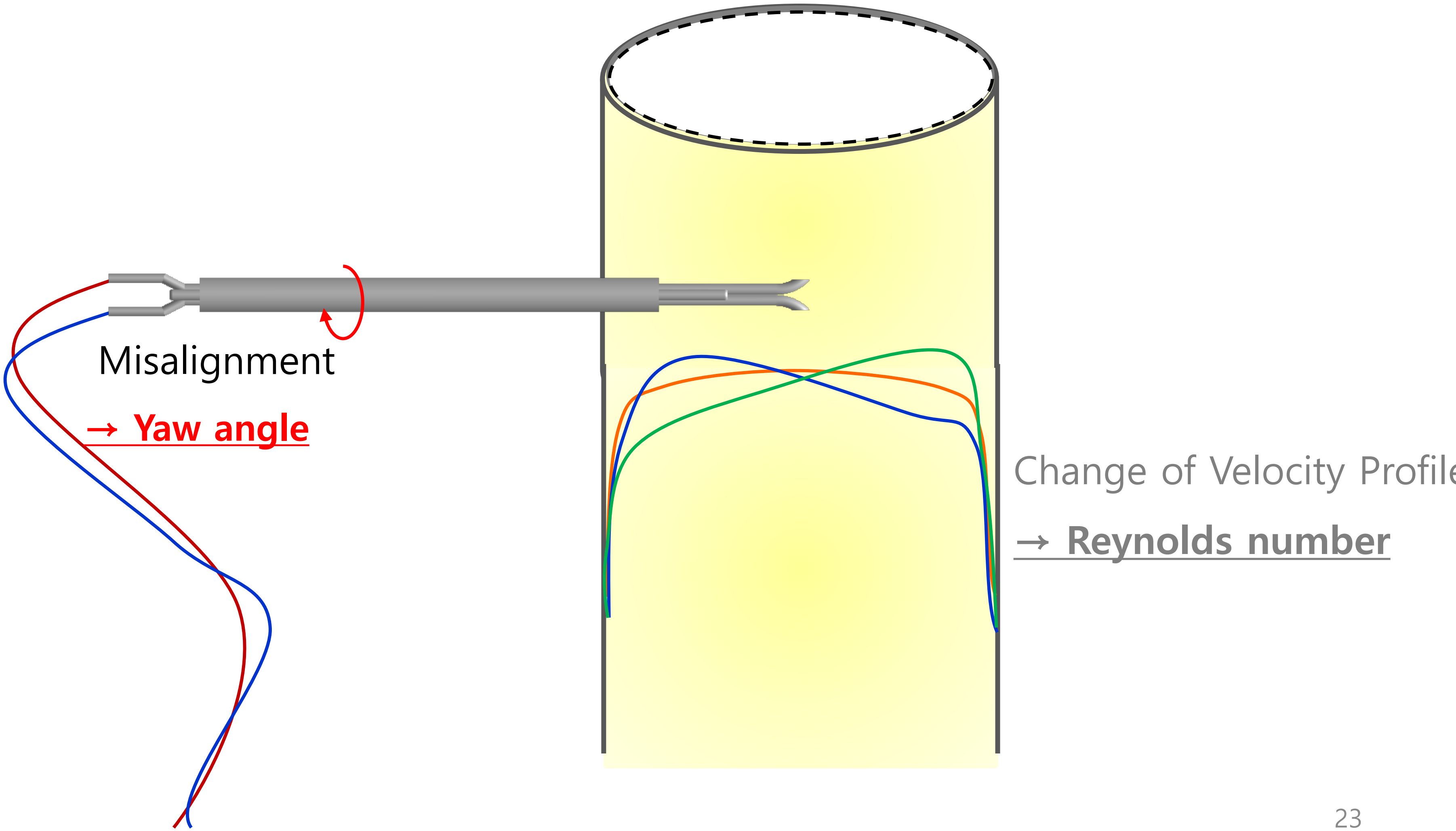
Change of Velocity Profile

→ Reynolds number

Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Background: What happen in the Stack?**

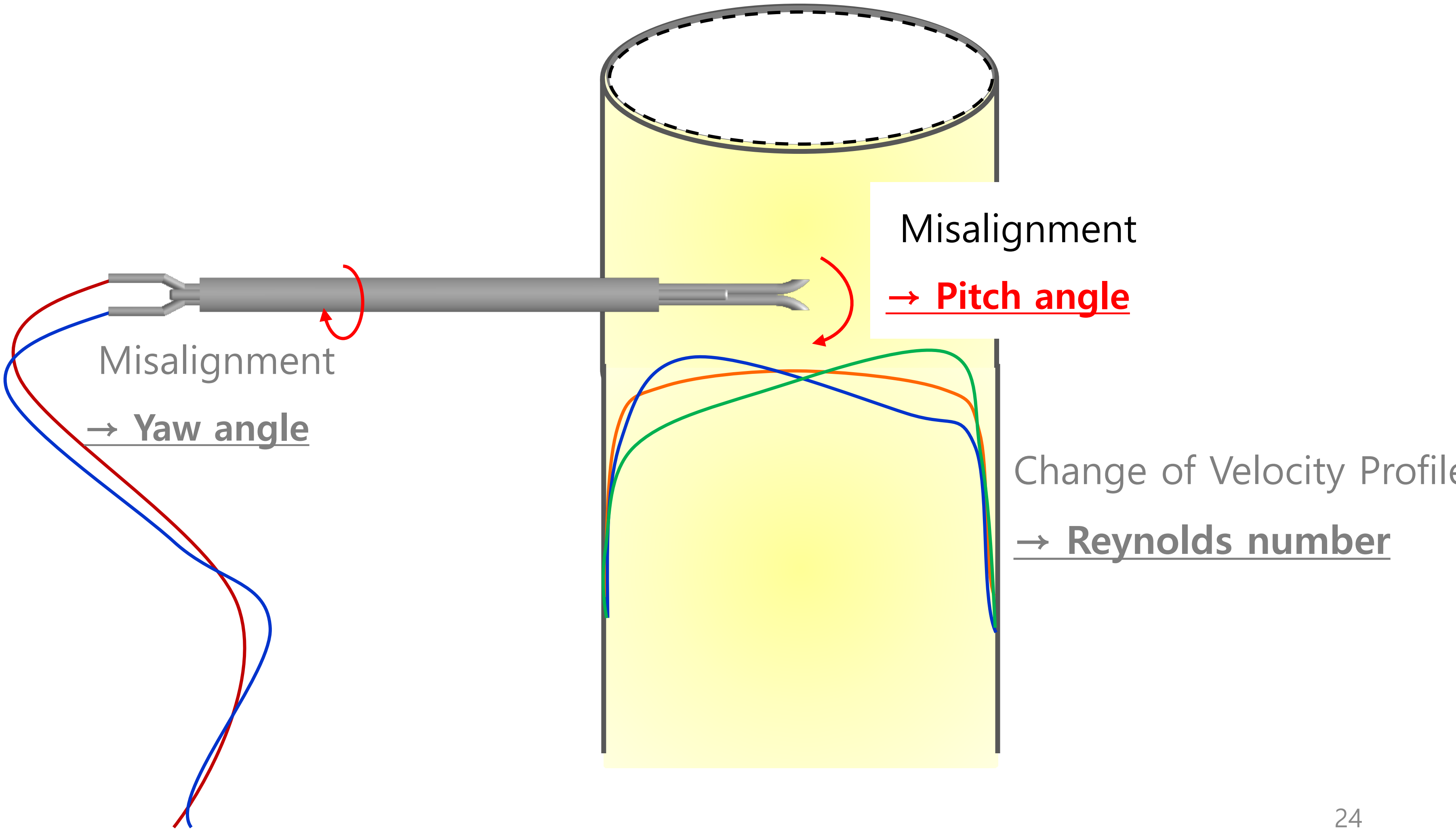
- Yaw angle misalignment can occur during installation of S-type Pitot tube from outside of the stack due to the difficulty of observation



Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- Background: What happen in the Stack?

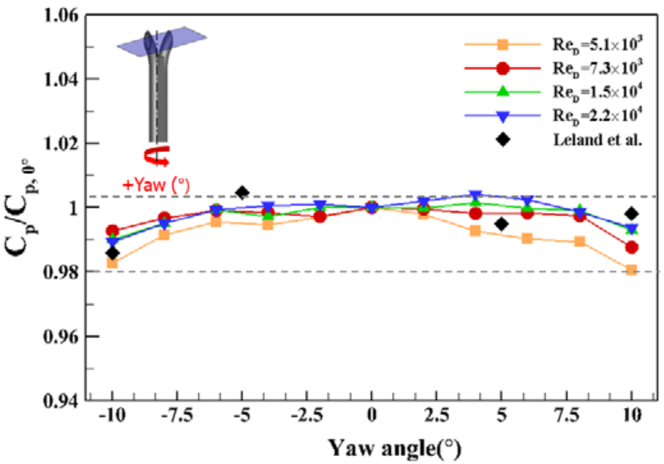
- Pitch angle misalignment of S-type Pitot tube can result due to the deflection of the long S-type Pitot tube in large diameter stacks.

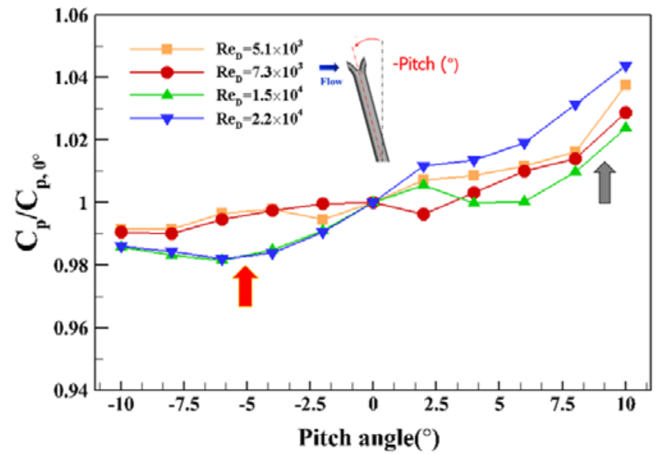


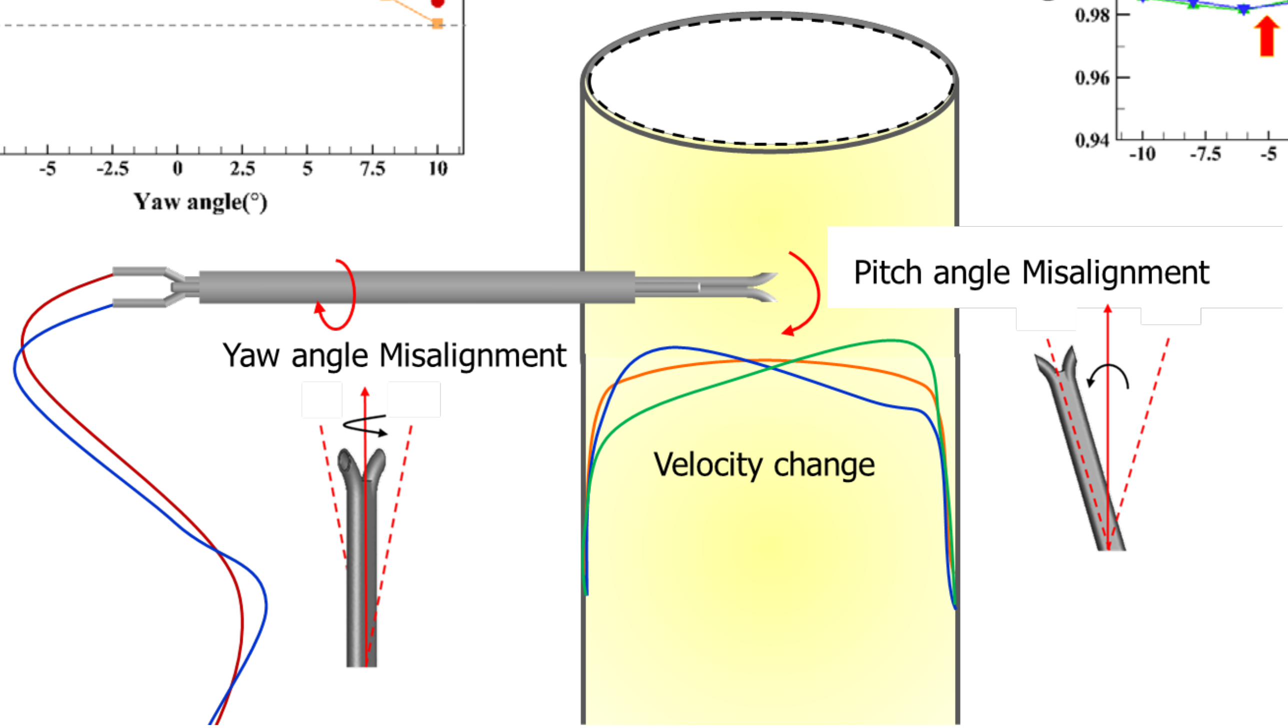
Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Background: What happen in the Stack?**

- When S-type Pitot tube install in the stack, there could be yaw, pitch angle misalignment and velocity change.
- But, one average calibration coefficient of S-type Pitot tube was used.



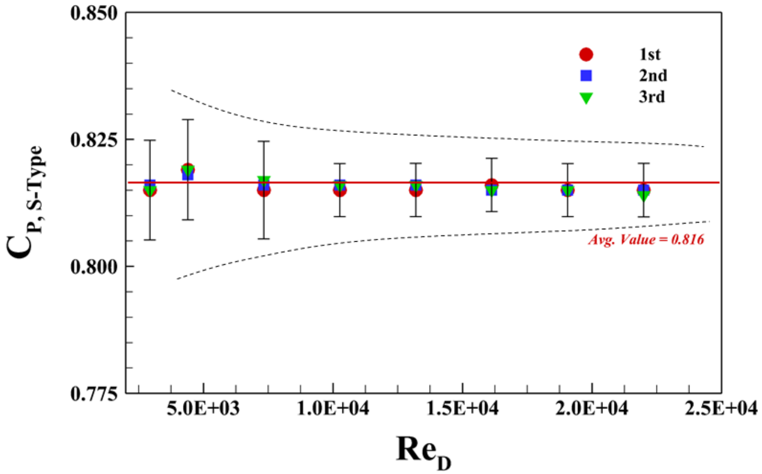




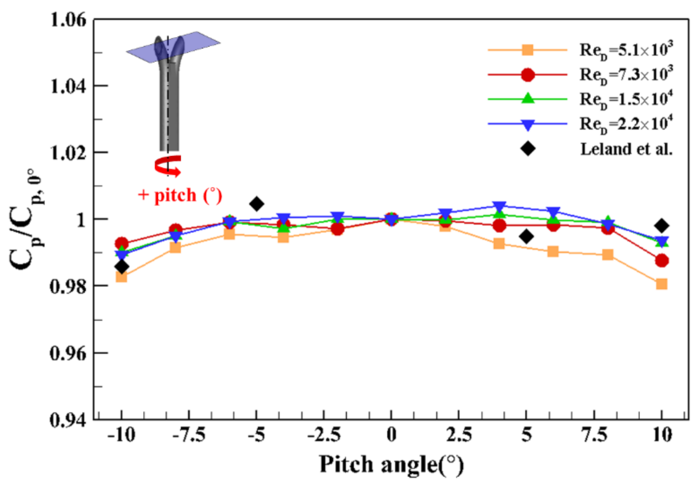
Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

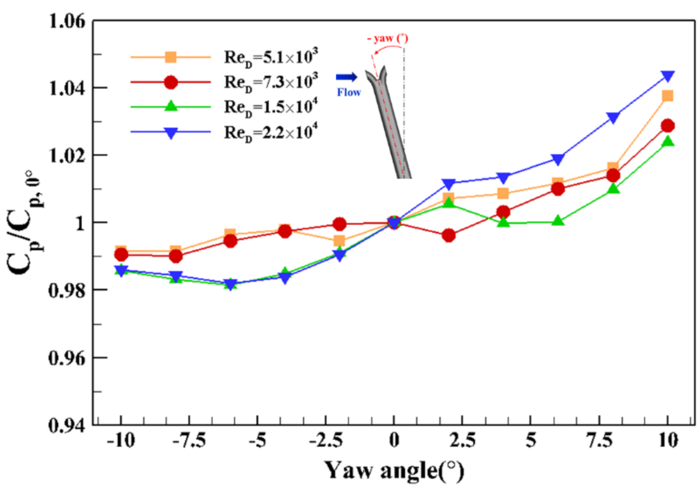
Background: What is ideal S-type Pitot tube?

- Linearity, Repeatability of S-type Pitot tube coefficient in the used range of Reynolds number



- Less (more) sensitivity to the effect of yaw and pitch angle misalignment

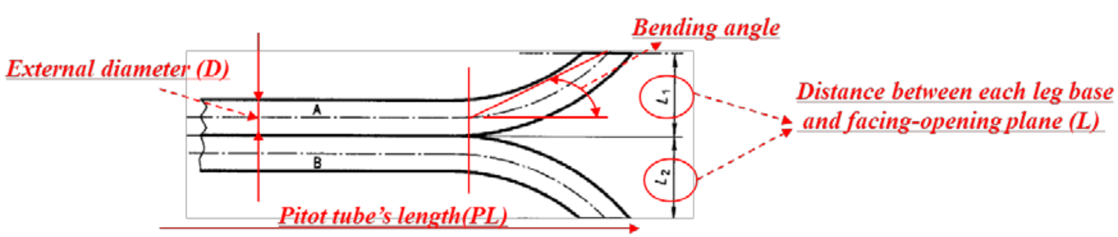




Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

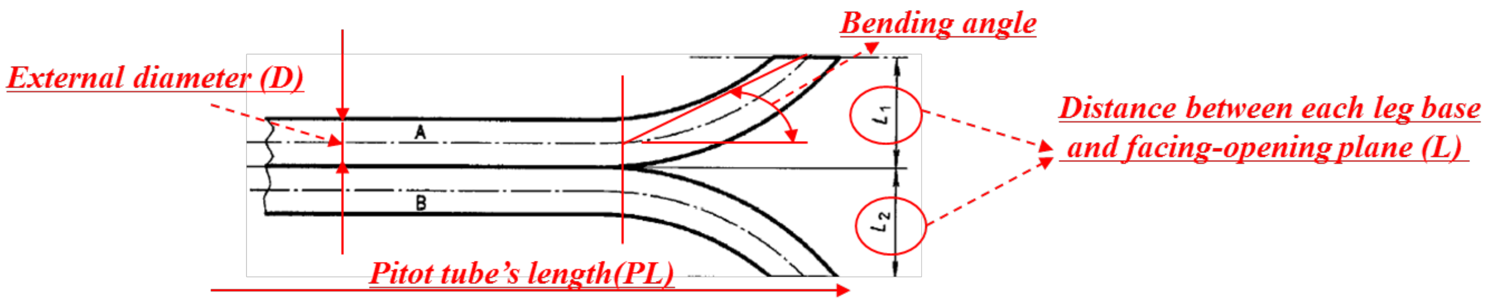
- **Guidelines are different between ISO and other standards**

ISO 10780	ASTM D3796(Ref. 1)	EPA
External diameter of leg (D) : 4 mm to 10 mm Distance between the base of each leg of the Pitot tube and its face-opening plane : 1.05D ≤ L ≤ 10D This distance shall be equal for each leg	Bending a 45° angle on the end of 0.95 cm stainless steel tube The Pitot tube's length : 0.6 m ≤ PL ≤ 3.0 m Cutting is parallel to the main body of the tube	External diameter of leg (D) : 4.8 mm to 9.5 mm Distance between the base of each leg of the Pitot tube and its face-opening plane : 1.05D ≤ L ≤ 1.50D This distance shall be equal for each leg



Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Parameters of optimum design**



1. Distance between leg base and opening plane (L)

- ISO: 1.05D ≤ L ≤ 10D, EPA: 1.05D ≤ L ≤ 1.5D

  → **L = 1.05D, 1.6D, 3D**

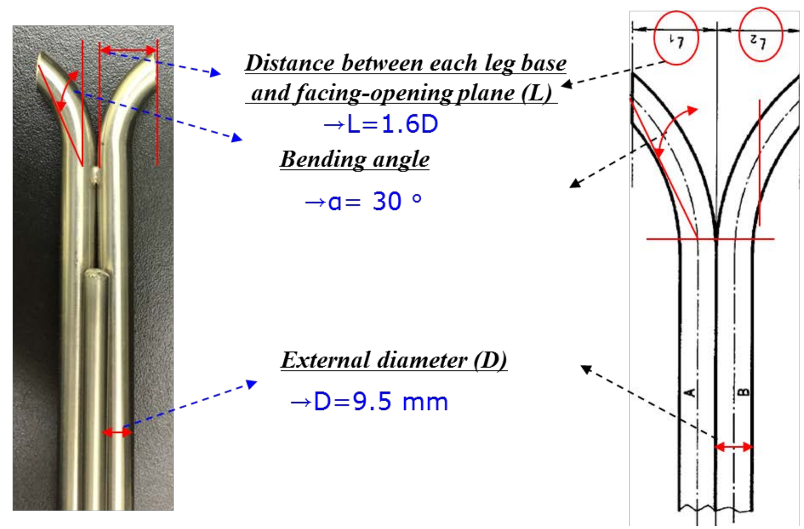
2. Bending angle of opening parts

- ASTM: 45° (KRISS S Pitot = 30 °)

  → **α = 15°, 30°, 45°**

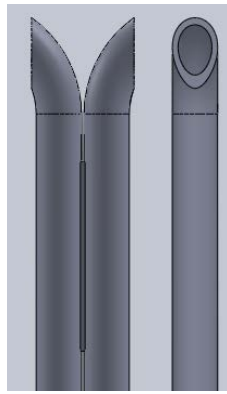
3. Shape of bending parts

→ **Curved, Straight**

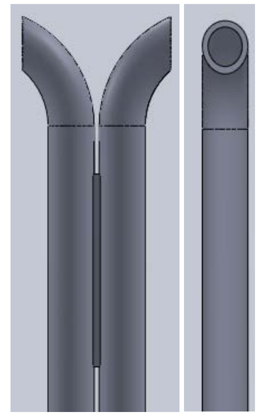


Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

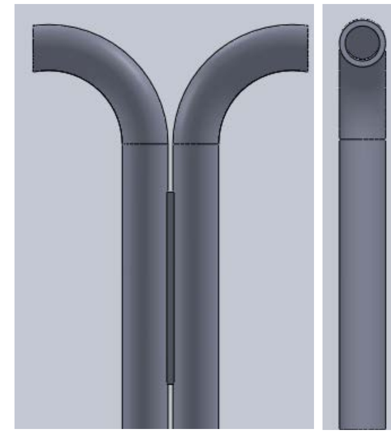
Design of S Pitot tubes



L =1.05D, α = 30°

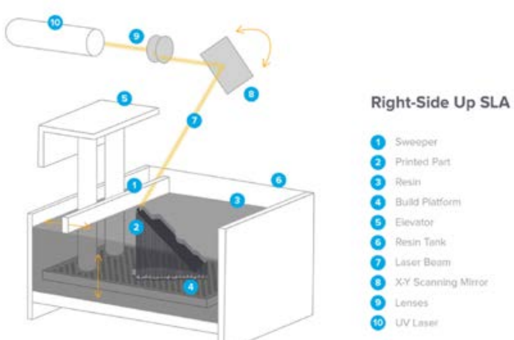


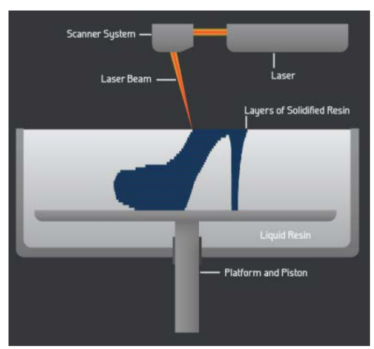
L = 1.6D, α = 30°

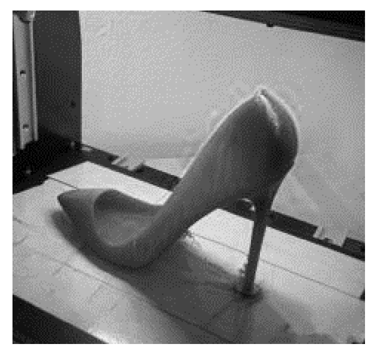


L = 3D, α = 30°

- **3D Printing (SLA, Stereo-lithography)**
  - focusing an ultraviolet (UV) laser on to a vat of photopolymer resin with elevator



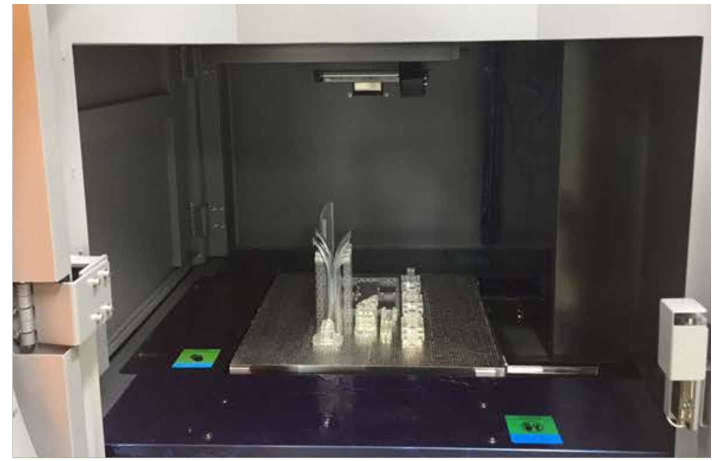


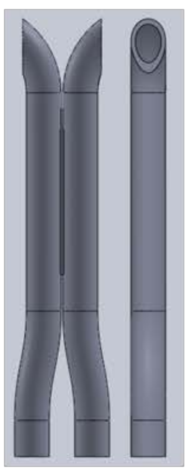


Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

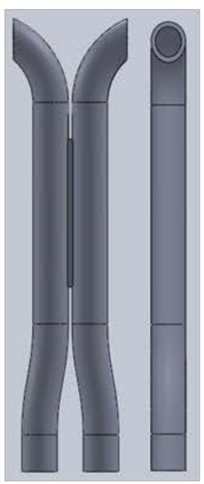
Manufacturing S tube by 3-D printer

Model	ATOMm-4000
Equipped Laser	Solid state laser 400mW 40KHz
Scanning Method	Digital (TSS4)
Laser Warranty Period	1 year
Maximum Scanning Speed	30,000mm/sec
Laser Diameter	0.10 - 0.60mm (automatically changeable)
Maximum Model Size	400×400×300mm
Z Table	Minimum layer pitch 25μm *depends on the resin used
Recoater	Blade recoater
Resin Surface Control	Balloon
Power Supply	AC100V×1 Single phase 15A
Equipment Dimension	Approx.W1565×D1050×H1860mm
Equipment Weight	Approx.550kg (not including resin)
Software	C-Sirius
PC OS	Windows 7
Operation	English/ Japanese

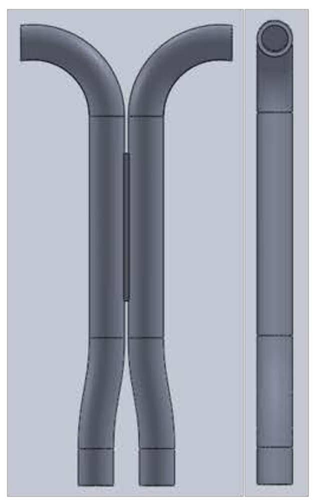




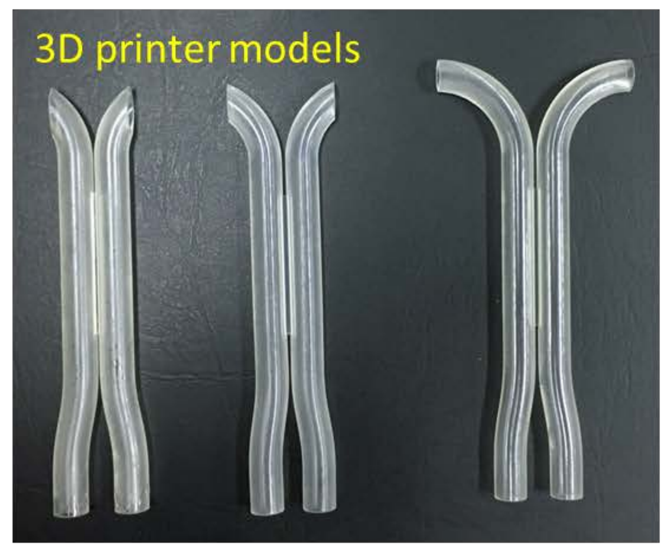
L =1.05D, $\alpha = 30^\circ$



L = 1.6D, $\alpha = 30^\circ$

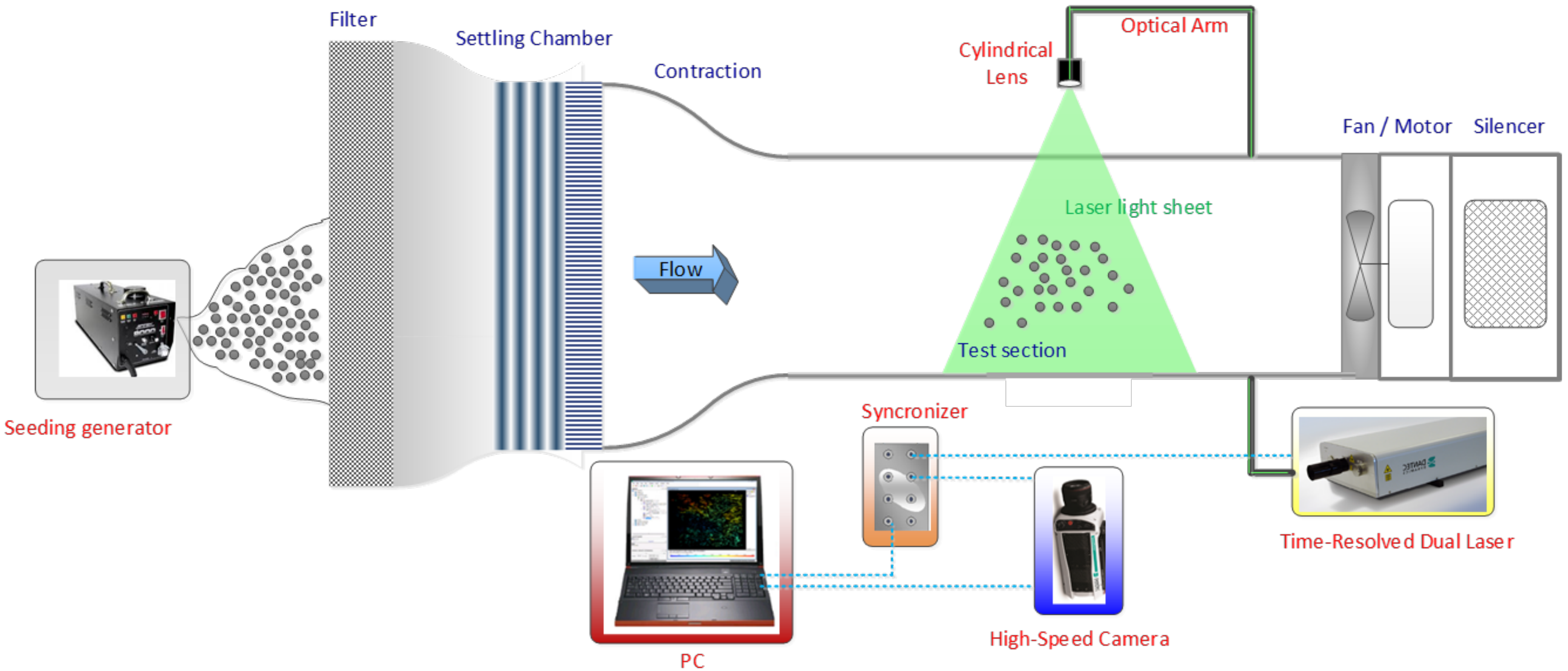


L = 3D, $\alpha = 30^\circ$



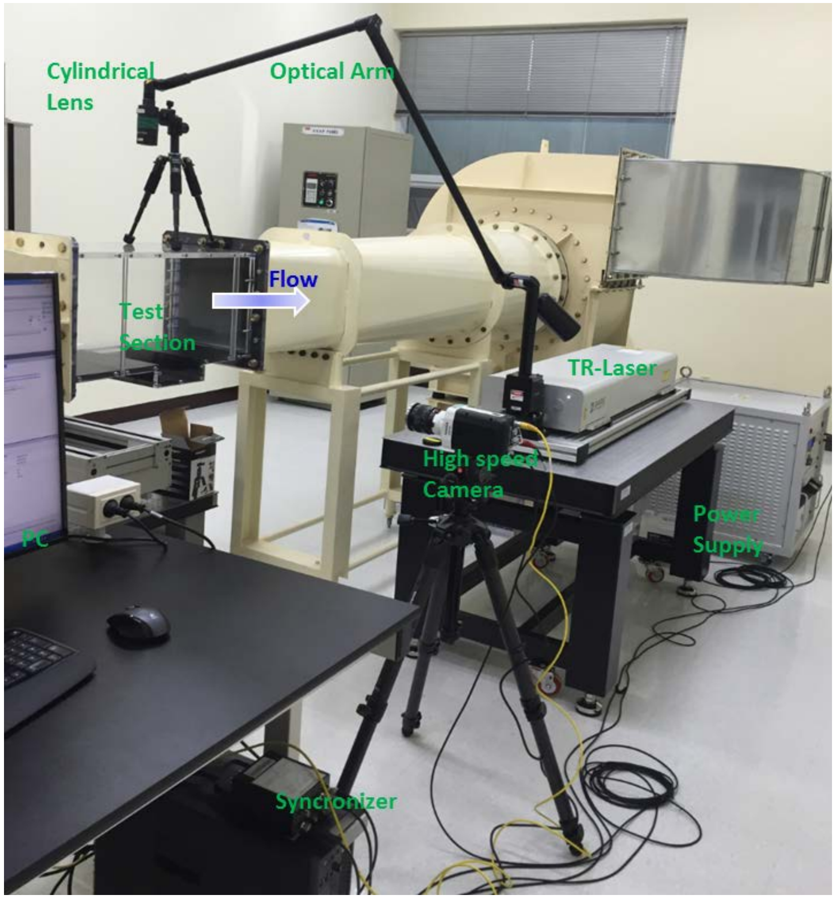
Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

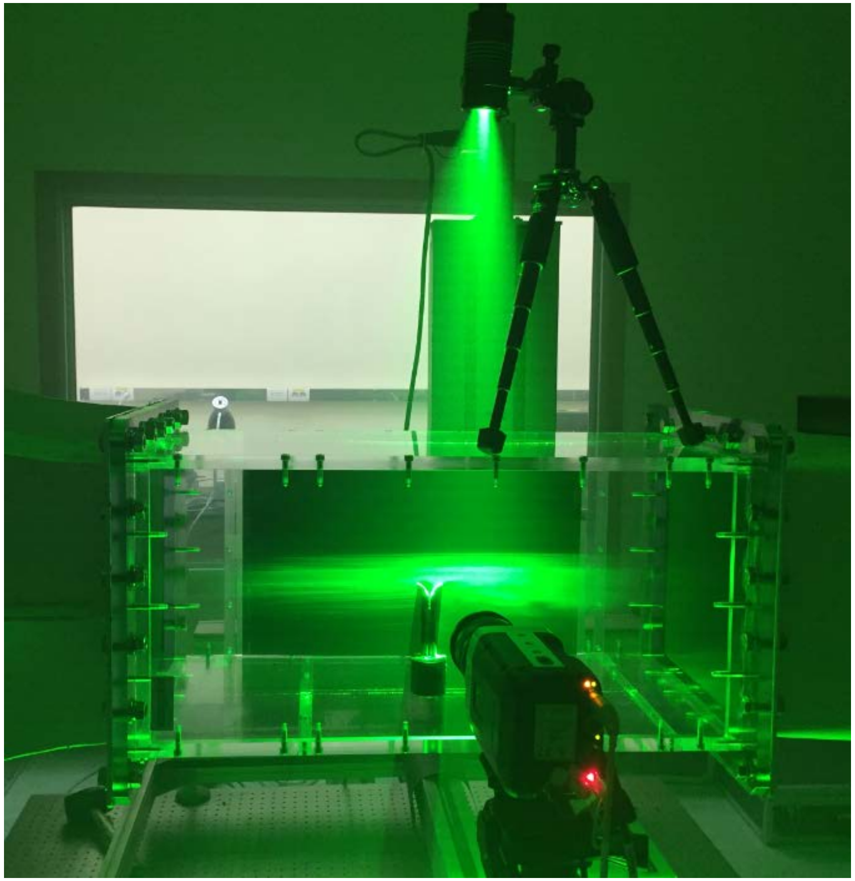
- Flow visualization around S Pitot by PIV



Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- Flow visualization around S Pitot by PIV

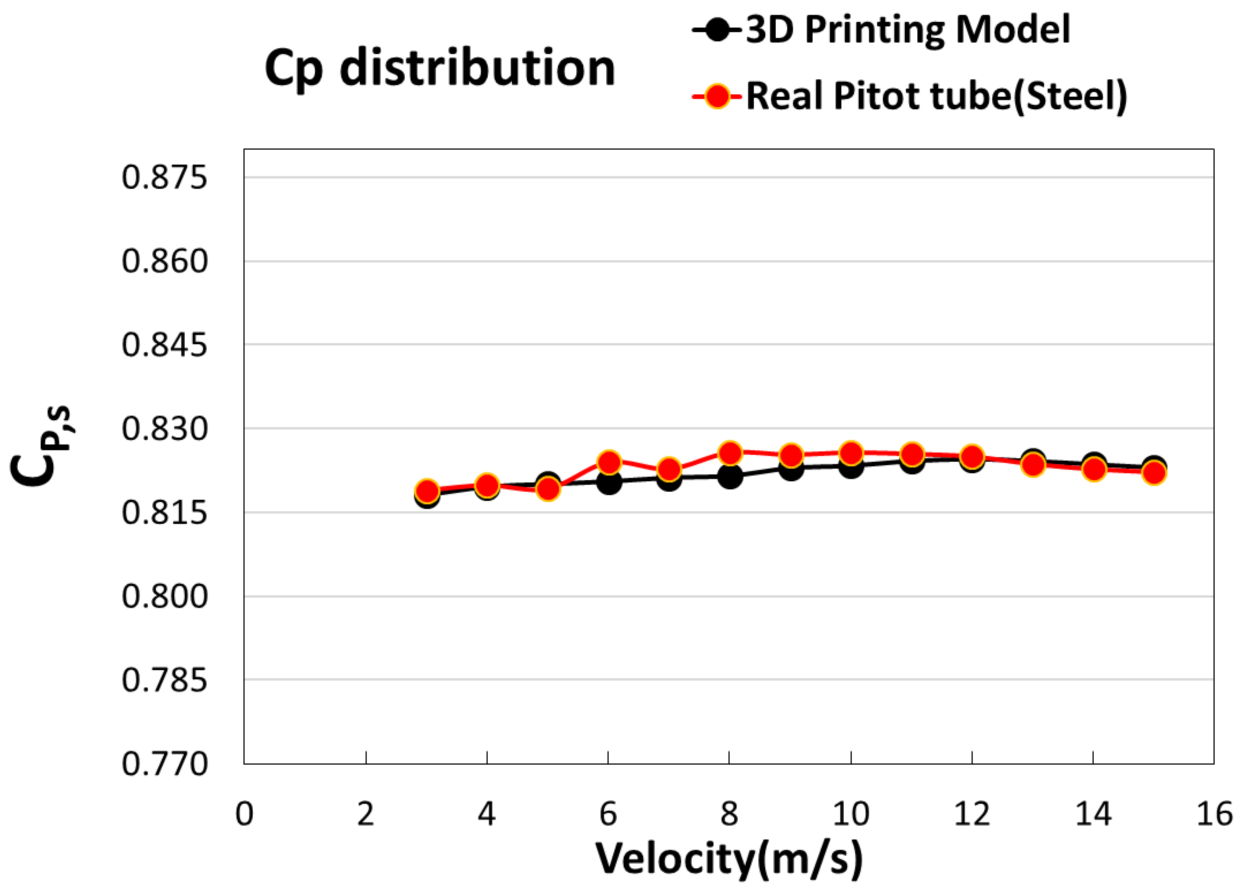




- Time-resolved laser (20 mJ), High-speed camera(3200 fps)
- Time interval = 1ms between two-consequent velocity image

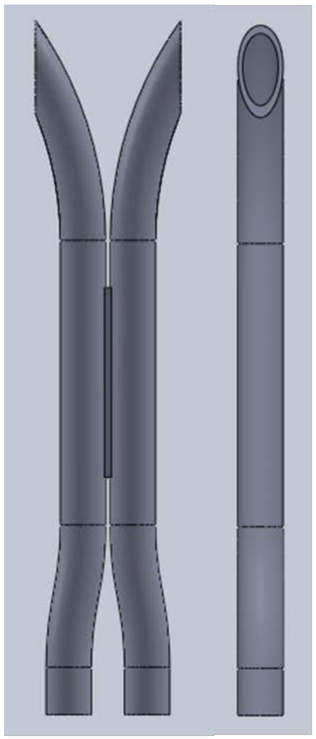
Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Verification of S Pitot by 3-D printing**

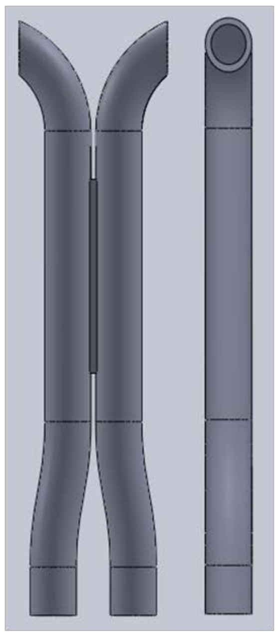


Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

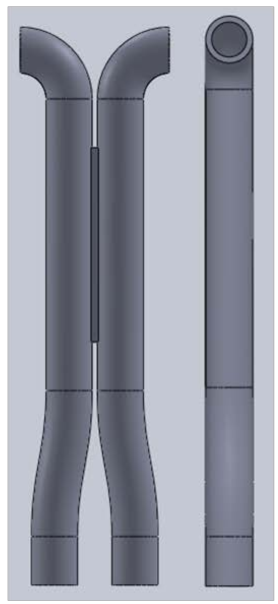
- **Pitot coefficients of S Pitot tube with L=1.6D**



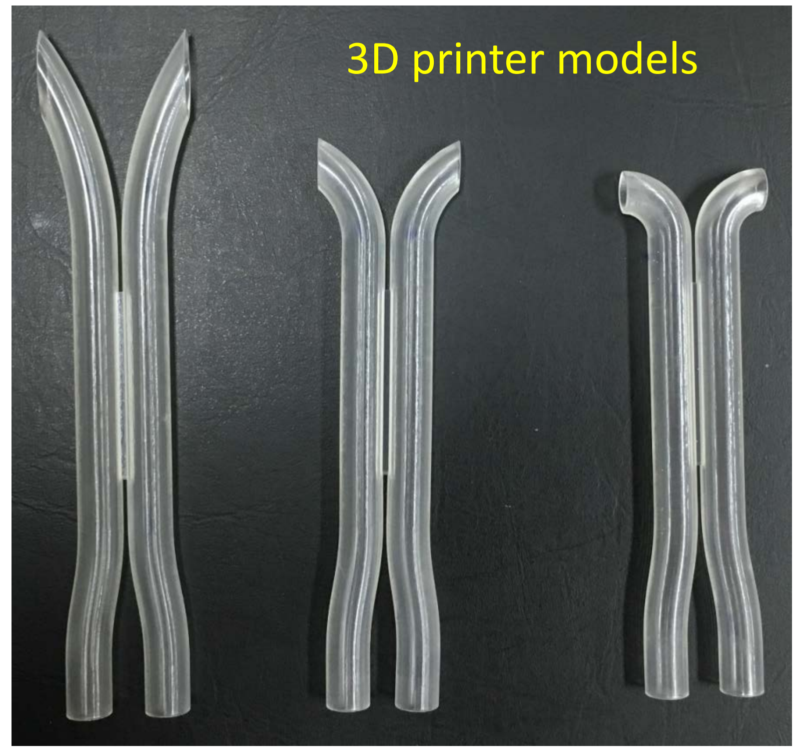
α = 15°, L = 1.6D



α = 30°, L = 1.6D

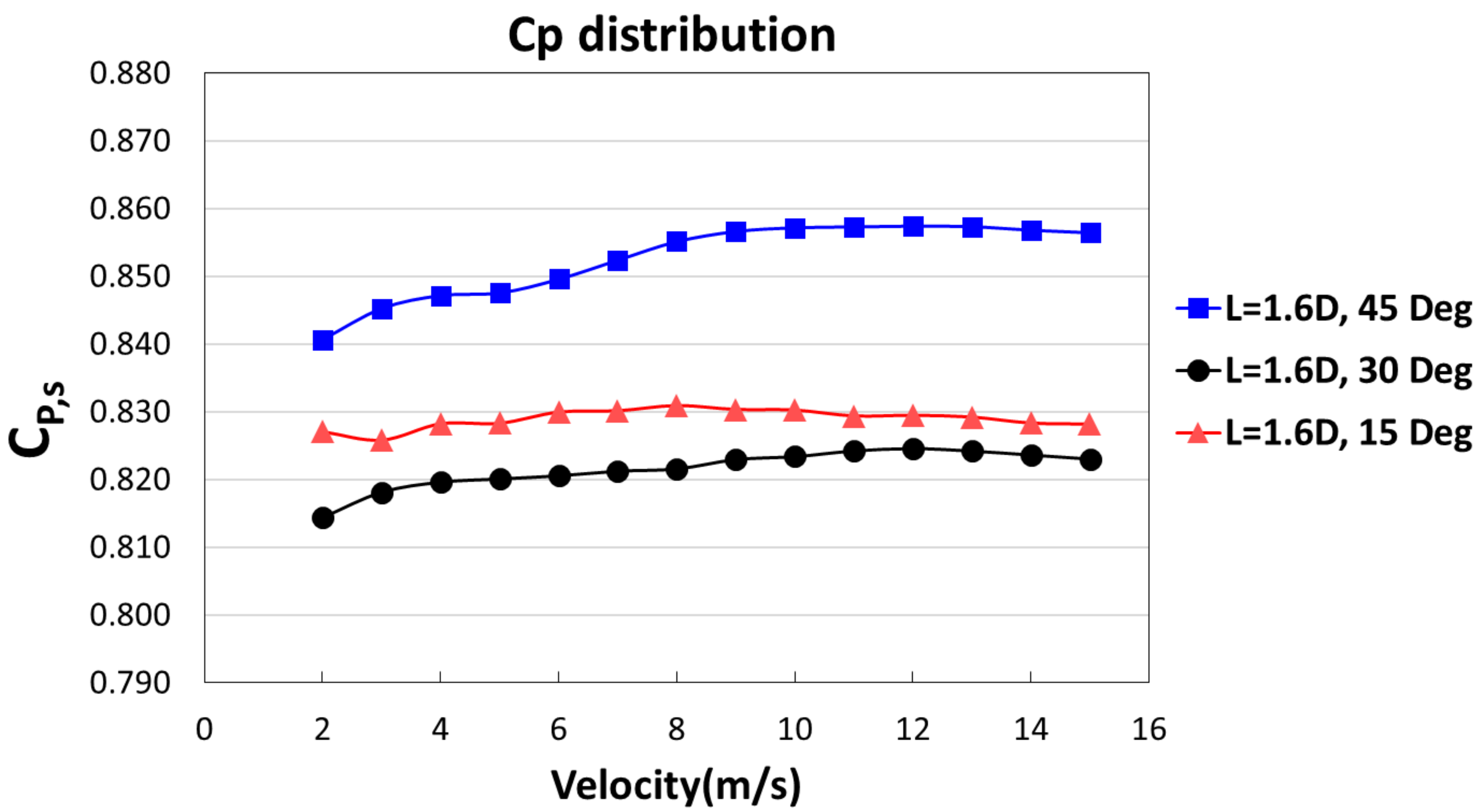


α = 45°, L = 1.6D



Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

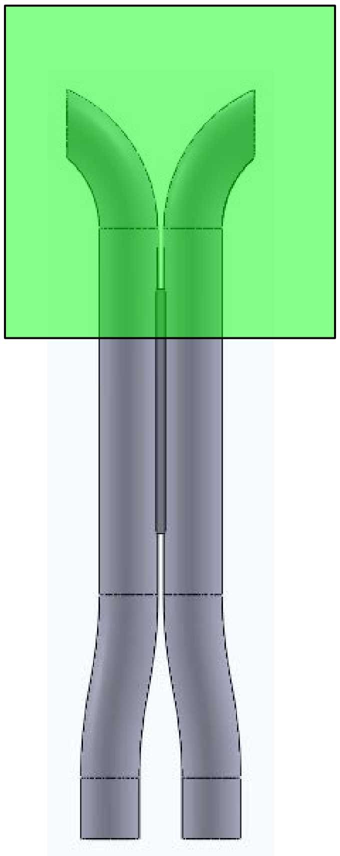
- Pitot coefficients of S Pitot tube with L=1.6D

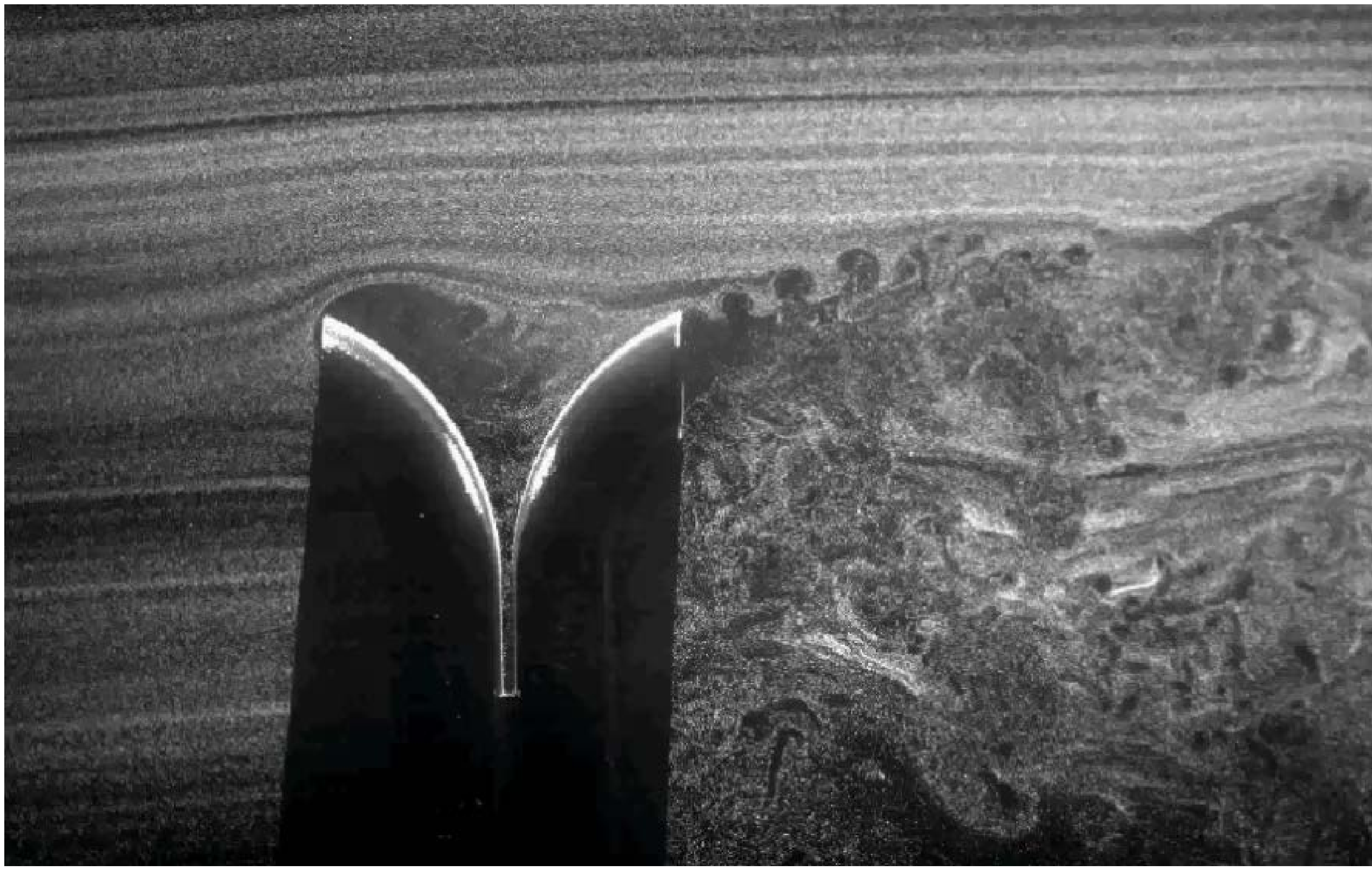


Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Flow around S Pitot tube L=1.6D, α=30˚**

- Flow around S-type Pitot tube



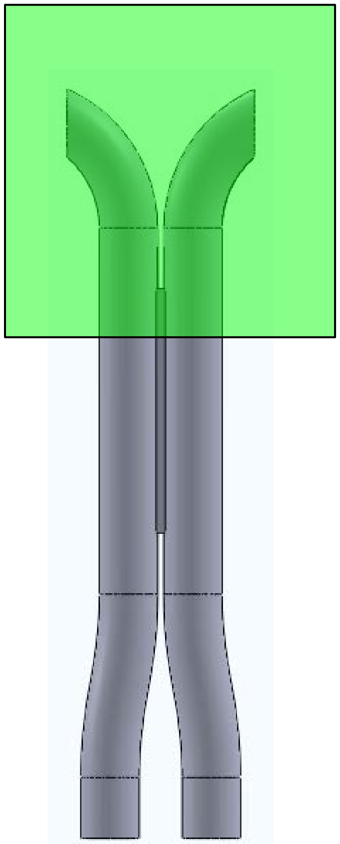


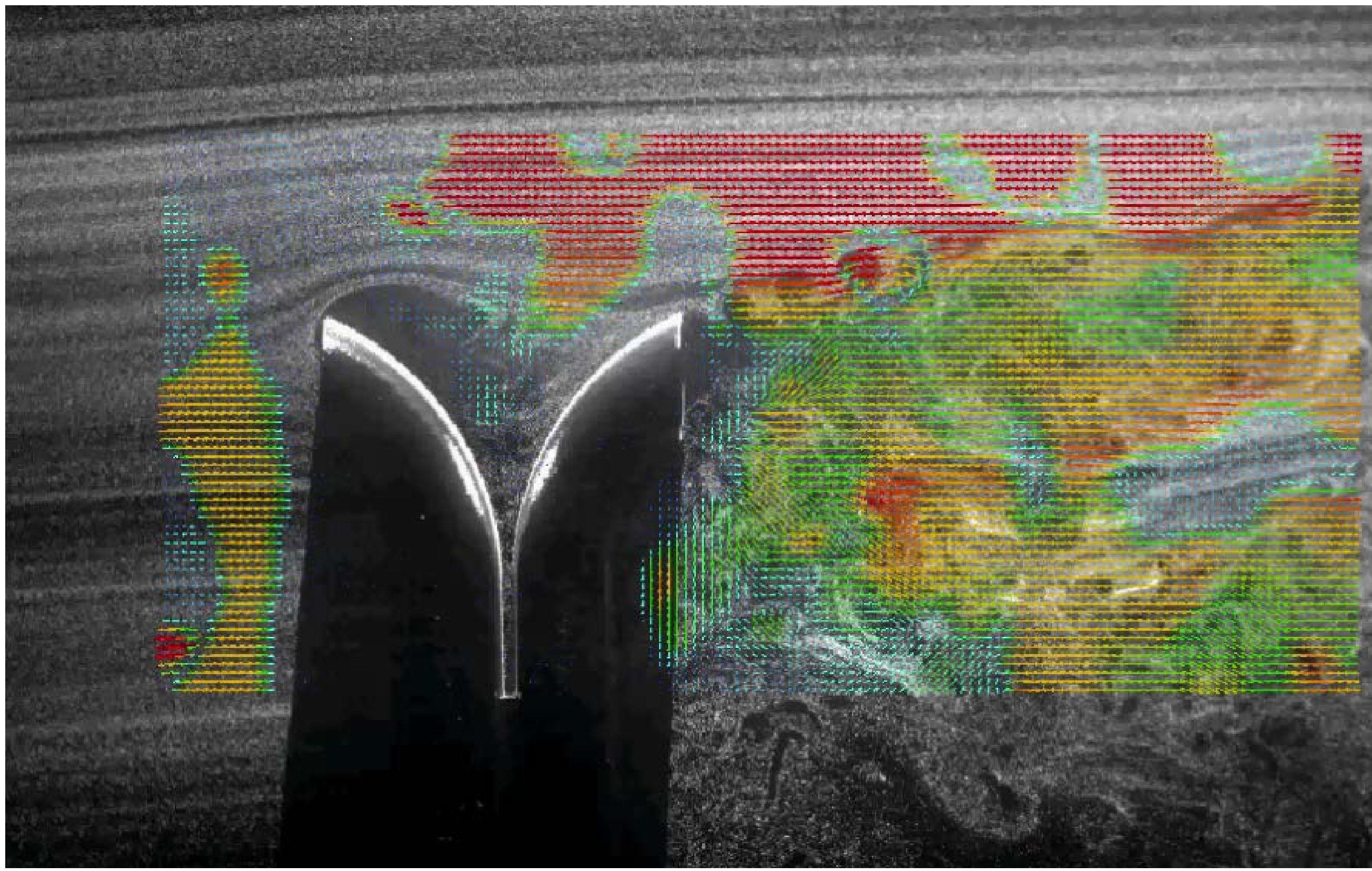
- Due to complicated geometry between the impact and wake orifices, the separated flow is developed to make vortical structure behind orifices

Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- **Flow around S Pitot tube L=1.6D, α=30˚**

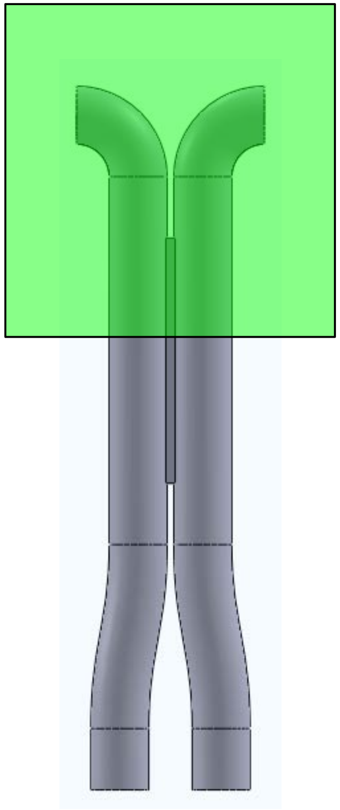
- Velocity vector distribution around S-type Pitot tube

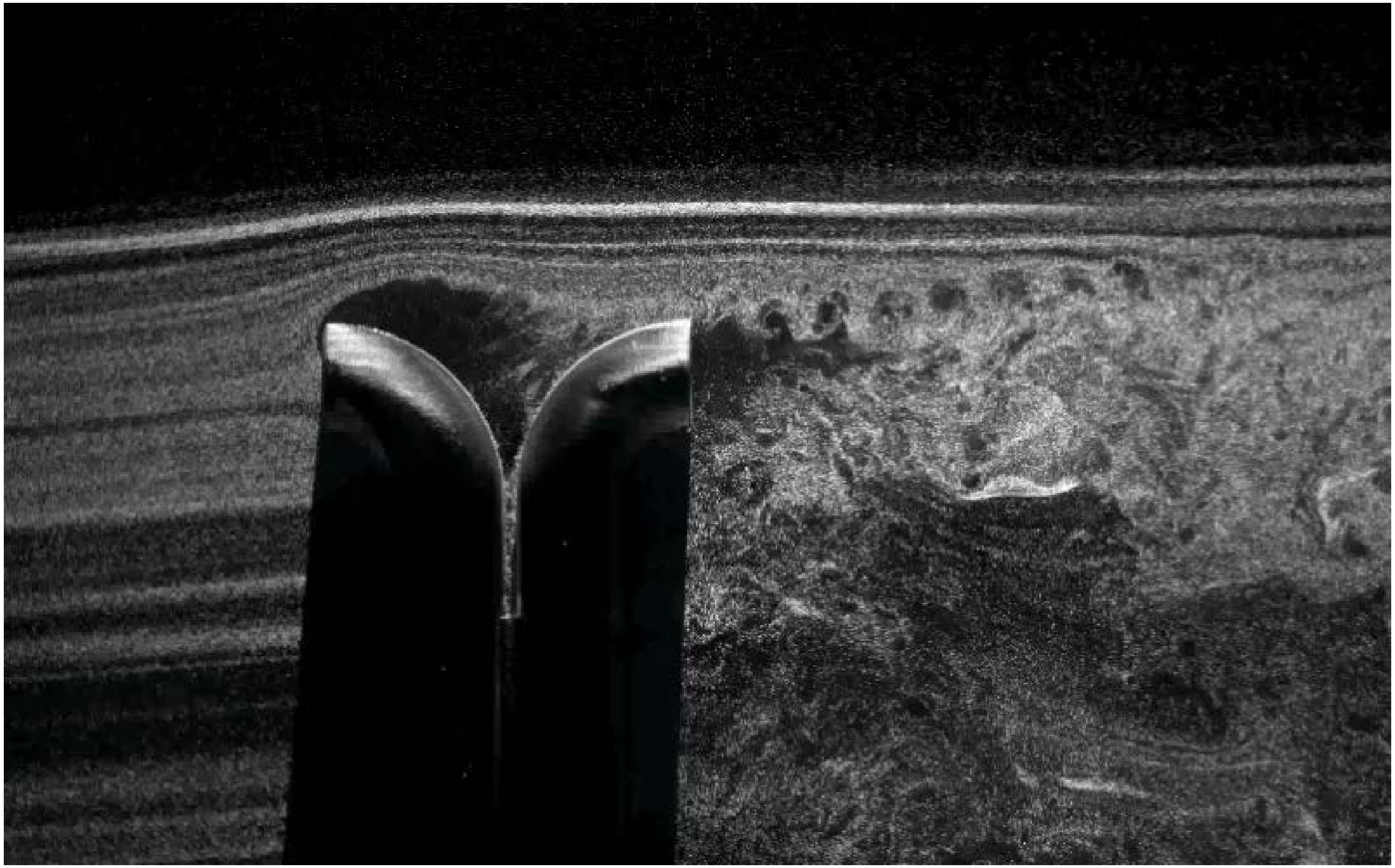




Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- Flow around S Pitot tube L=1.6D, α=45˚



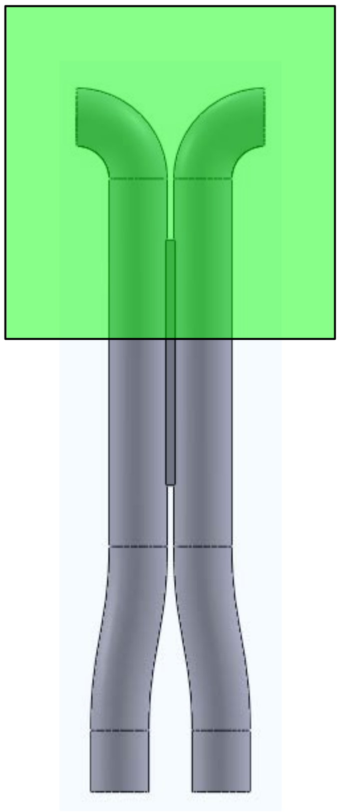


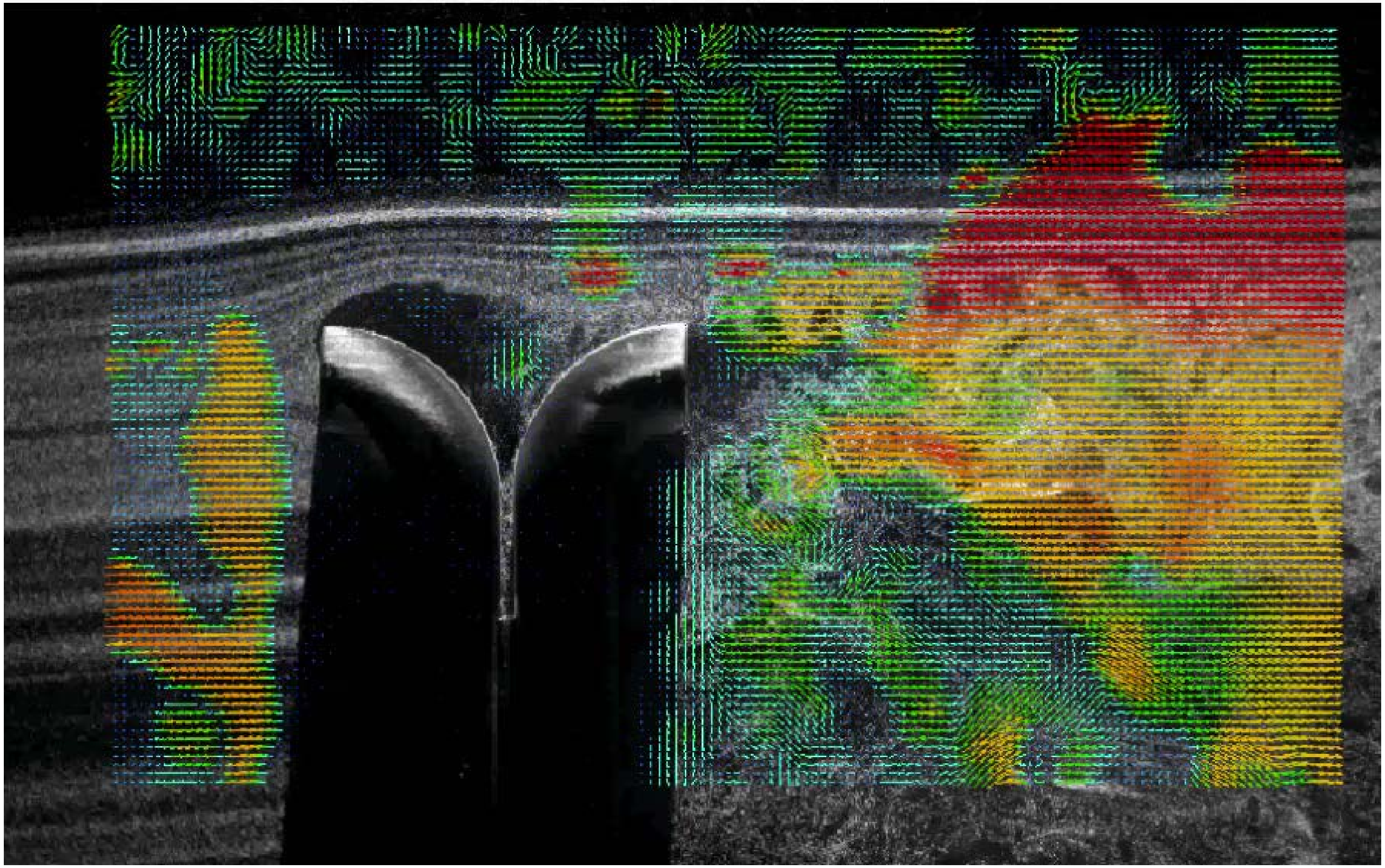
- Separated flow from wake orifice(downstream) is developing less due to gradual change of curved surface comparing with 30˚ model.

Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- Flow around S Pitot tube L=1.6D, α=45˚

- Velocity vector distribution around S-type Pitot tube

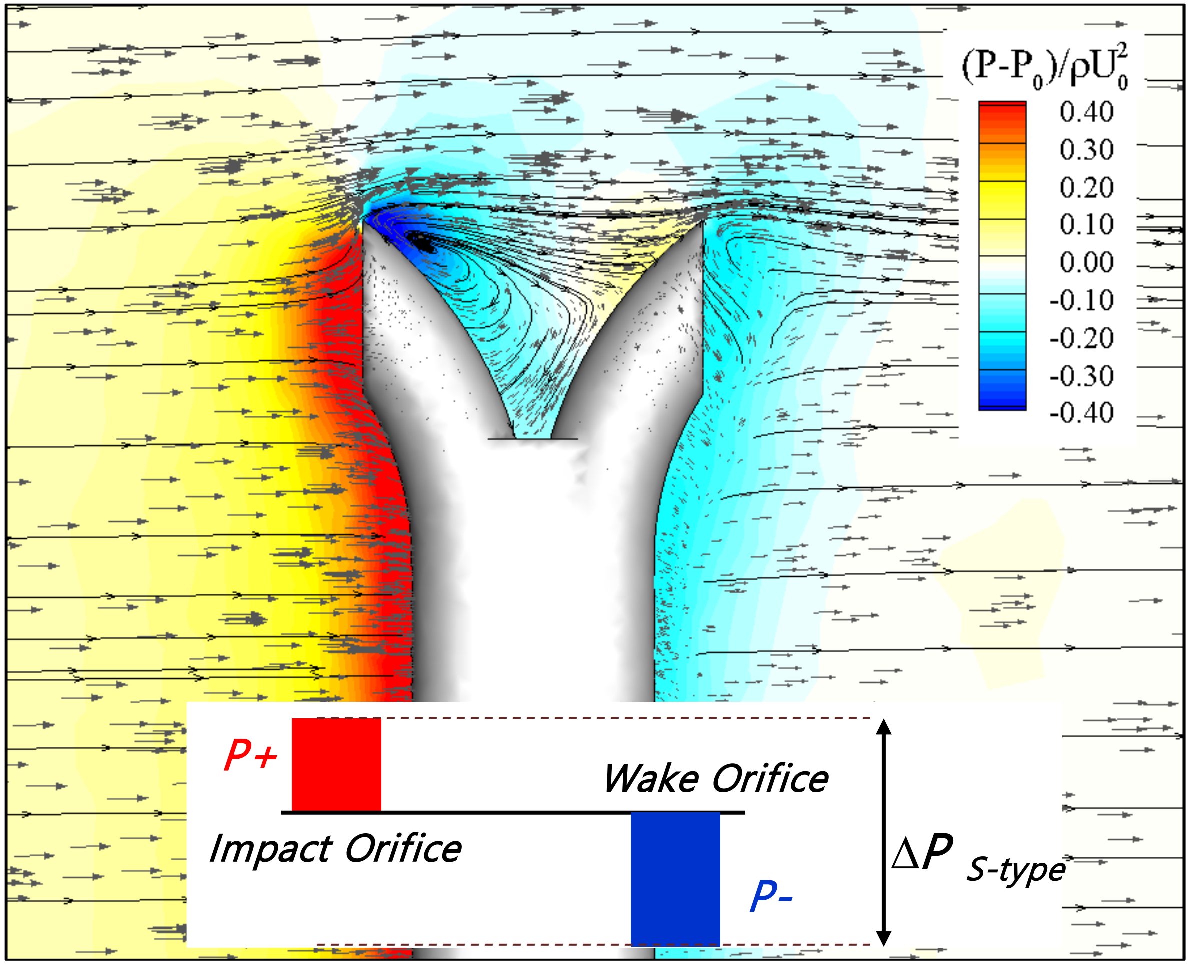




Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- When vortical structure behind the wake orifice developed well
- Lower pressure at wake orifice → ΔPs increase → Cp,s decrease

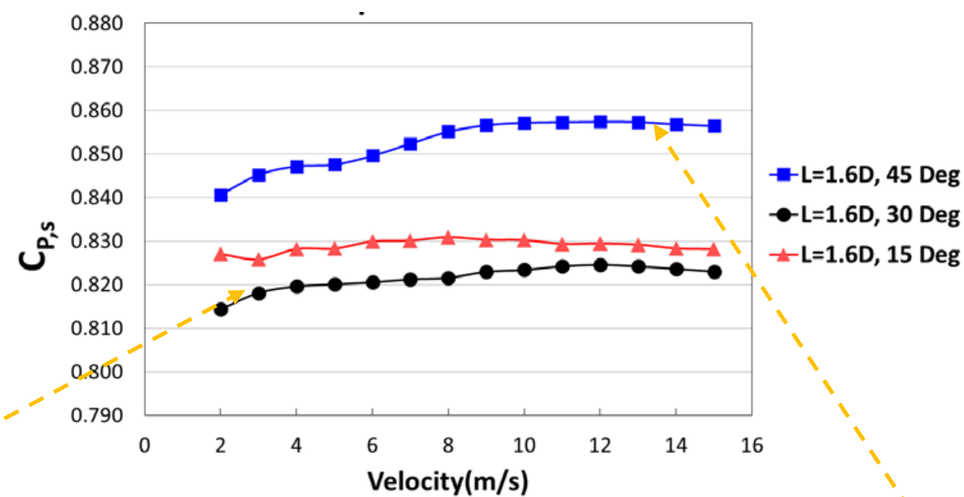
$$C_{P,S} = C_{P,Std}\left(\frac{\Delta P_{Std}}{\Delta P_{S\cdot type}}\right)$$

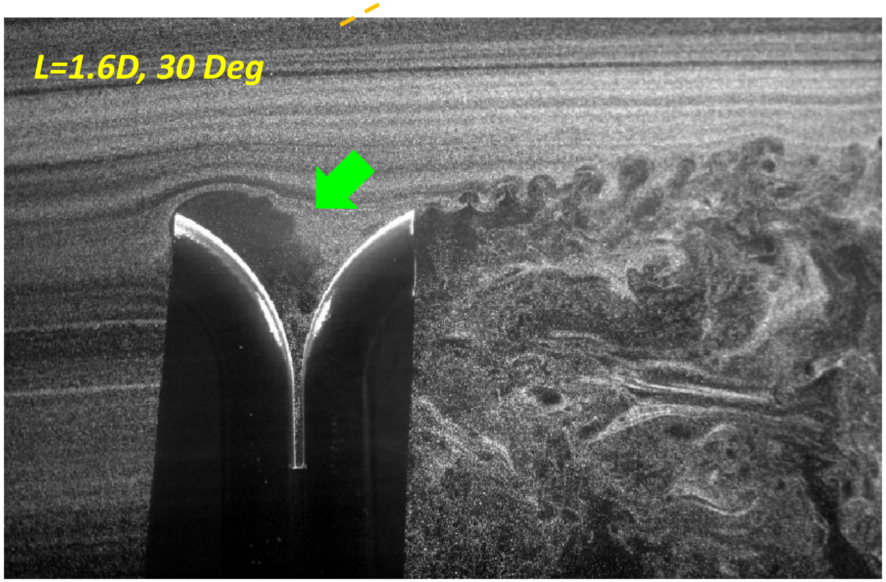


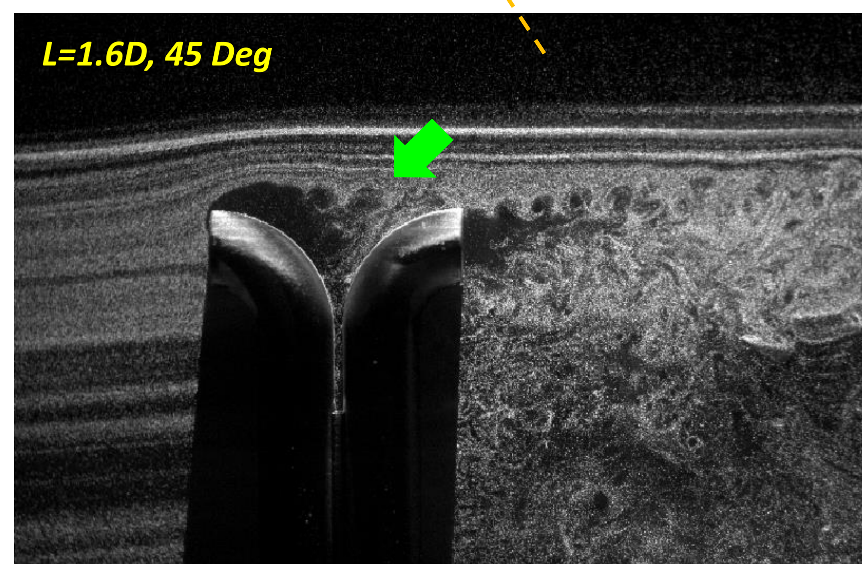
Numerical simulation
FMI, Kang et al. 2015

Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- Separated flow from wake orifice(downstream) is developing less due to gradual change of curved surface → Cp,s increased (45 deg)







Air Speed in KRISS: Optimum Shape of S-type Pitot Tube

- Work is continuing for changing the Pitch and Yaw angle
- Needs more test for the effect of geometry

1. Distance between leg base and facing-opening plane (L)

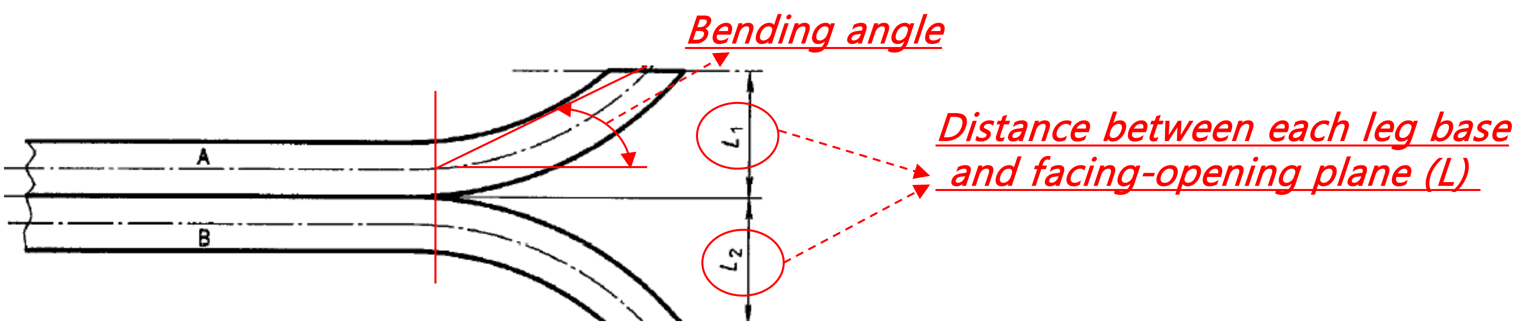
→ **L = 1.05D, 1.6D, 3D**

2. Bending Angle of opening parts

→ **α = 15°, 30°, 45°**

3. Shape of opening parts

→ **Curved, Straight**



1. Air Speed in Korea, HCT, Calibration Lab of KOLAS

- HCT (www.hct.co.kr) is the testing and calibration company
- Accredited as Test Lab by KOLAS and the other accreditation body

FCC (미국연방통신위원회) FCC (Federal Communications Commission, USA)	CE (유럽공동체마크) CE (European Community Mark)	ISED (혁신과 과학경제 발전처) ISED (Innovation, Science ands Economic Development)	IECEE CBTL (국제전기기기인증제도) IECEE CBTL (International Electro-Technical Commission)

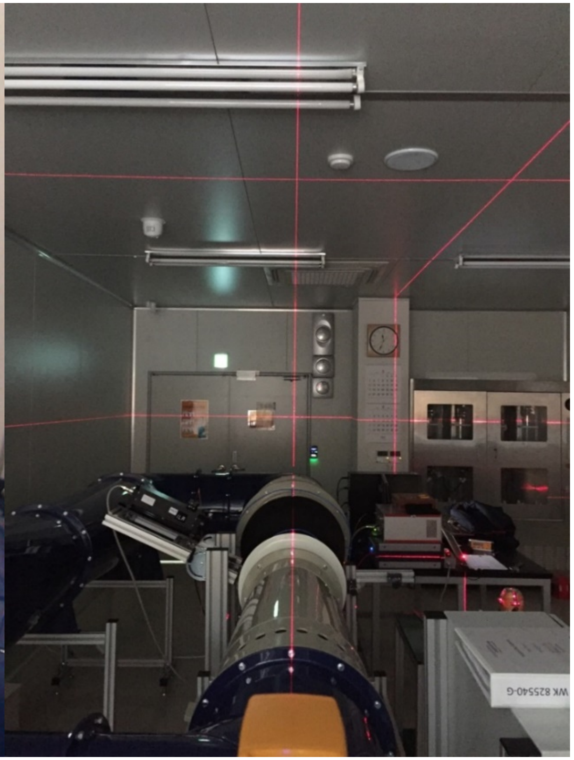
A2LA (미국 시험기관인정기구) A2LA (American Association for Lab.oratory Accreditation, USA)	CTIA (미국 셀룰러통신산업협회) CTIA (Cellular Telecommunication Industry Association, USA)	CEC (캘리포니아 에너지 위원회) CEC (California Energy Commission, USA)	TUV Rheinland (유럽 제품성능 및 안전인증) TUV Rheinland (Product Safety and Quality Certification, Europe)	TELEPERMIT (뉴질랜드 유선통신) TELEPERMIT (New Zealand Wired Communications)	CRA (이란 정보통신인증) CRA (Information & Communications Accreditation in Iran)
VCCI (일본전자파장애 자율규격협의회) VCCI (Voluntary Control Council for Interference, Japan)	TUV SUD CARAT (유럽 안전규격인증) TUV SUD CARAT (Safety Standard, Europe)	PHOENIX TESTLAB PHOENIX TESTLAB (In Germany)	NATA RTA (호주 국제인증전문업체) NATA RTA (National Association of Testing Authorities, Australia)	OFCA (홍콩 이동통신인증) OFCA (Office of Communications Authority, Hong Kong)	ICASA (남아프리카공화국 독립통신위원회) ICASA (Independent Communications Association in South Africa)

Air Speed in Korea, HCT

Pride KRISS Since 1975

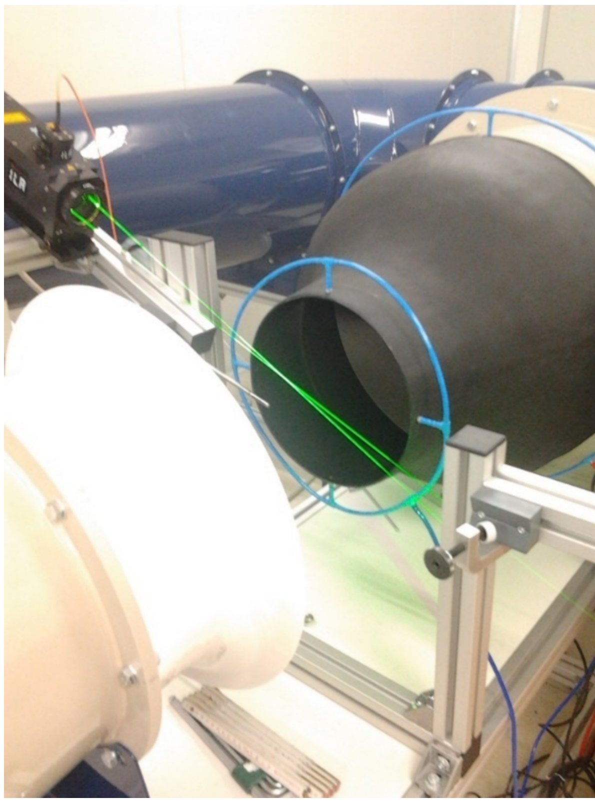
- **Air speed is accredited on Aug. 2017 by KOLAS**
- **Closed type wind tunnel with 1-D LDA**

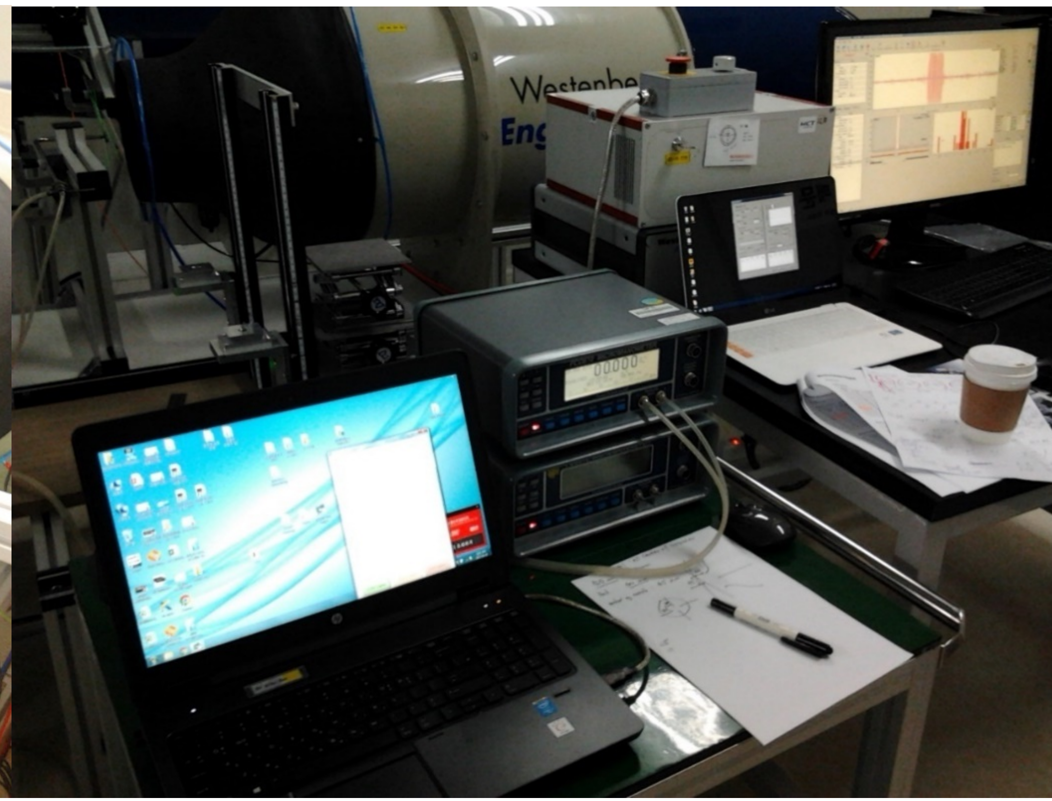
- **Test section: 255 mm Circular with open Test Section**
- **Turbulence intensity is below 1 %**
- **Quality of air speed distribution within 1 %, from 0.1 m/s to 40 m/s**



Air Speed in Korea, HCT

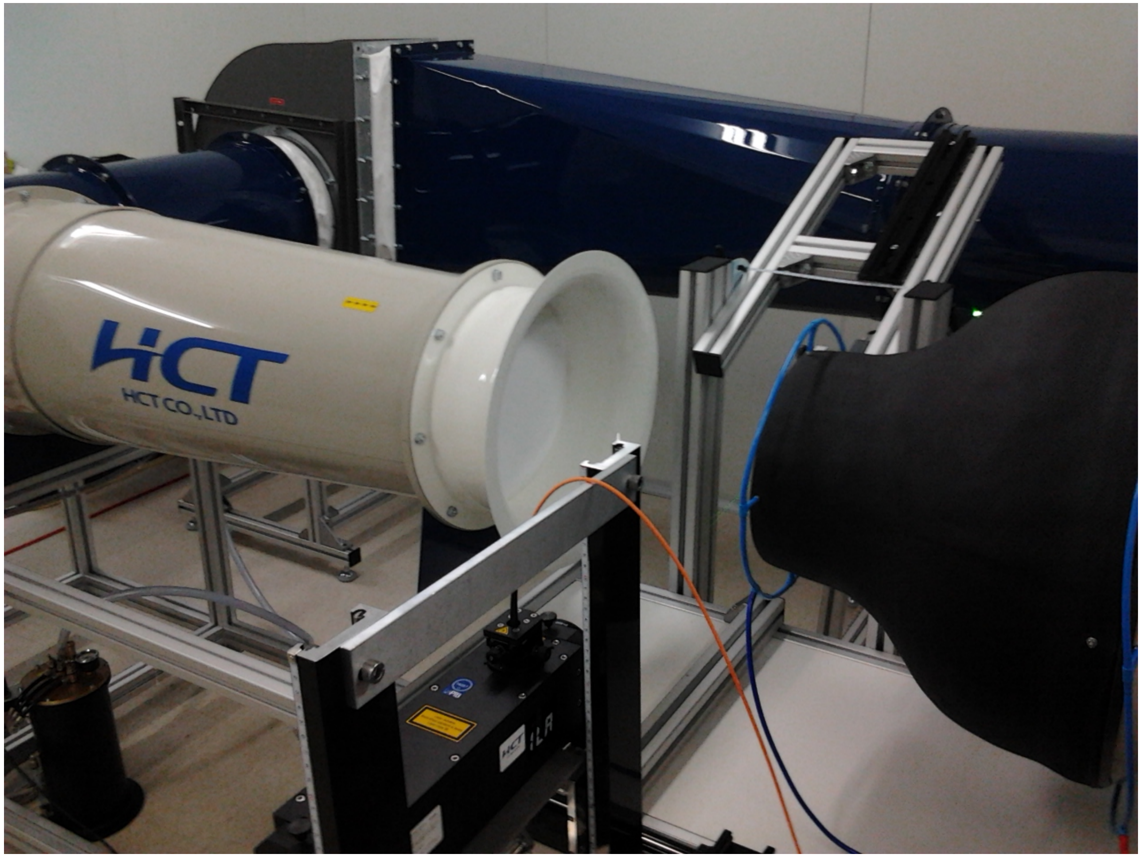
- **Velocity distribution, turbulence intensity and stability is tested by KRISS**
- **Uncertainty estimation of LDA and CMC of air speed evaluated by KRISS**





Air Speed in Korea, HCT

- How to make low air speed below 2 m/s is …
- One or two sponge is located in front of the receiving bell mouth

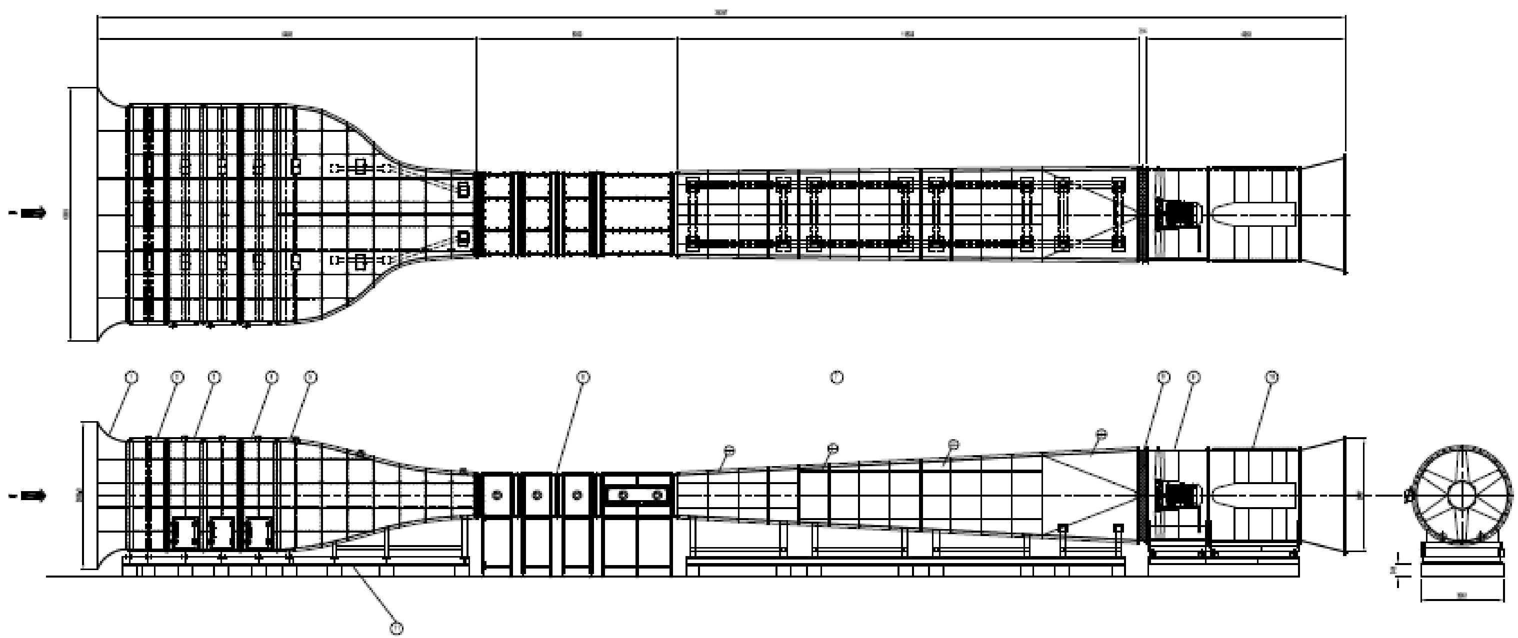


2. Air Speed in Korea, KECO (Korea Environment Corporation)

- KECO(www.keco.or.kr) is the agency for environment protection department of Korean Government. Main functions are;
  - Management and treatment of waste water
  - Management and treatment of waste materials
  - Monitoring and control the waste gas
  - Monitoring and control the air and water quality

Air Speed in Korea, KECO

- Set up in Sep. 2006 for anemometers in stacks for GHGs
- Suction type wind tunnel, NPL Pitot tube with DP sensors
  - **Test section: 2000(W) x 1000 (H) x 5000 (L) mm, Contraction ratio 7.2:1**
  - **Turbulence intensity: 0.5 %**
  - **Air speed distribution: 1 %, from 2.0 m/s to 40 m/s**



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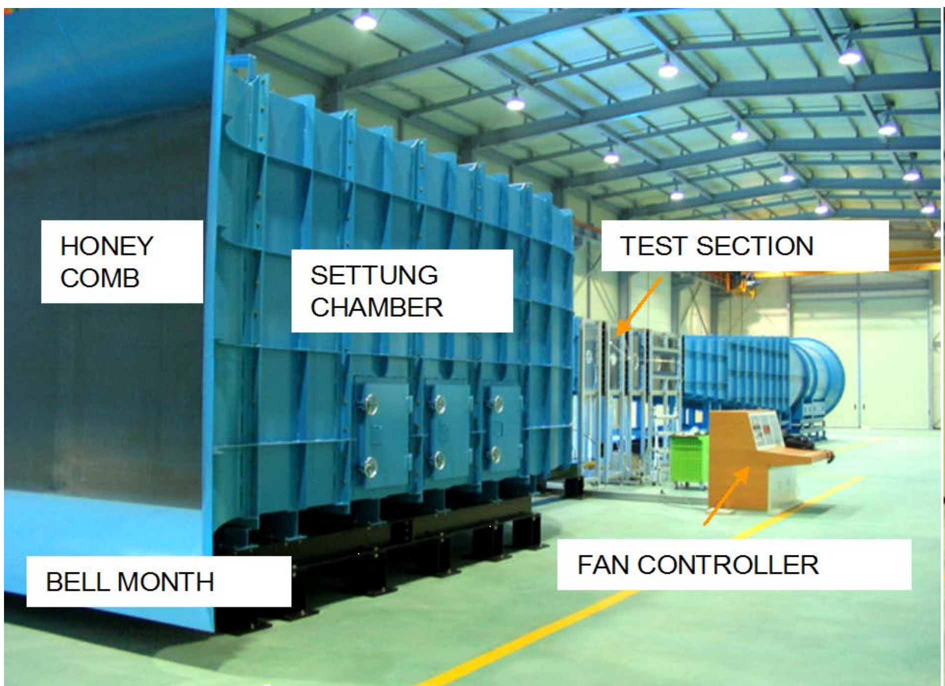

Air Speed in Korea, KECO

Guideline of Performance test for S-Type Pitot Tube

- **Operation test: no failure within 7 days**
- **Zero drift: below 2 % in 7 days**
- **Span drift: below 2.5 % in 7 days**
- **Minimum detecting velocity: below 1 m/s**
- **Accuracy and Repeatability Test: better than 2 %**
- **Linearity test: better than 5 %**
- **Angle of Yaw and Pitch Test: ± 10° with in 4 %**
- Response time: below 2 min

3. Air Speed in Korea, KMA(Korea Meteorological Agency

- Typhoon Maemi 60 m/s in Pusan on Sep 21, 2003

ⓒPhoto by Pusan-Ilbo

Air Speed in Korea, KMA

- KMA(www.kma.go.kr) built new wind tunnel with V=75 m/s on 2006
- Closed type wind tunnel, NPL Pitot tube with DP sensors
  - **Test section: 1000 x 1000 mm**
  - **Turbulence intensity is below 1 % with Two Motors**
  - **Quality of air speed distribution within 1 %, from 2.0 m/s to 75 m/s**

Pride KRISS
Since 1975

고맙습니다!

Thanks you!