MEASUREMENTS OF SOOTBLOWER JET STRENGTH IN KRAFT RECOVERY BOILERS – PART II: RESULTS OF THE 3rd AND 4th FIELD TRIALS

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ABSTRACT

Two additional field trial studies were conducted in different kraft recovery boilers in Sweden using force-measurement probes to determine the force of sootblower jets under various blowing conditions. The results confirm the findings of previous trials that at a given distance, the force exerted on a target by a fully expanded sootblower jet increases nearly linearly with an increase in lance pressure. At a given lance pressure, the jet force decreases drastically as the distance between the sootblower nozzle and the target increases. At a distance farther than 1 m (3 ft) from the nozzle, the jet retains less than 10% of its original strength. The studies also show clearly that the size and shape of the target have a significant effect on the force exerted on it by the jet. At a given projected area, a flat surface receives a greater force from the jet than a target with an inclined surface.

DEDICATION

This paper is dedicated to Kari Saviharju of Andritz who initiated the project and helped bring it to fruition. Mr. Saviharju died of cancer in December 2008.

BACKGROUND

Sootblowers are used to remove fireside deposits from heat transfer surfaces in kraft recovery boilers; as such they are of vital importance for the thermal performance and production capacity of the boilers. The ability of a sootblower jet to remove a deposit is directly related to the jet strength (or force) exerted on the deposit during blowing. While many studies have been performed over the past two decades to examine jet characteristics and interaction with tubes and deposits, most was performed under well controlled conditions in the laboratory [1-3]. In late 2007, a collaborative project was initiated by Andritz to systematically measure sootblower jet strength in-situ [4]. The study involved designing and constructing two force-measurement systems and using them to determine the jet force directly in operating recovery boilers. Prior to this, no similar study has been reported in the literature owing understandably to the harsh environment in the boilers.

The objectives of this study were to obtain field data on jet strength, compare them with laboratory data, and to use them to validate the SJT (Sootblower Jet Turbulence) model that has been developed over the years at the University of Toronto for predicting the behavior of sootblower jets [5,6]. A total of four field trials were conducted. The first three trials (Trials 1, 2 and 3) were carried out in a recovery boiler at the SCA packaging mill in Obbola, Sweden, while the 4th trial (Trial 4) was in a recovery boiler at the Södra Cell mill in Värö, Sweden. The force-measurement probe design, test procedures, and the results obtained from the first two trials (Part I of the project) have been discussed in detail in a paper published recently in TAPPI Journal by Saviharju et al. [4]. The main conclusions obtained in Part I were that at a given sootblowing lance pressure, the jet force diminished markedly with an increase in distance between the sootblower nozzle and the target. At 1 m (3 feet) from the nozzle, the jet exerted only 10% of its maximum possible force on the same target. At a longer distance, the jet struck the target not only with a weaker force but also for a shorter period of time.

These trials also showed that the jet strength fluctuated widely, particularly when the jet was close to the target. The fluctuation was due mainly to the vibration of the target as it was struck by the jet, and to a lesser extent, to the change in jet strength caused by platen swinging, and the tremor of the system that held the target. The surrounding flue gas temperature was found to have an insignificant effect on jet strength.

This paper concerns Part 2 of the collaborative project, involving Trial 3 in which different target sizes and shapes were used, and Trial 4 in a different recovery boiler using a different design of force-measurement system.

TRIAL 3

Trial 3 was performed in November 2008 in the same recovery boiler as Trials 1 and 2 at the Obbola kraft mill. This is a small recovery boiler: the distance between the front wall and the nearest sootblower in the superheater region is only 3.5 m (11.5 ft). With a 4.4 m (14.4 ft) long force-measurement probe inserted through the front wall of the boiler (Figure 1), it was possible to determine the sootblower jet force at any distance up to 2.5 m (8.2 ft) between the sootblower nozzle and the target plate of the probe.

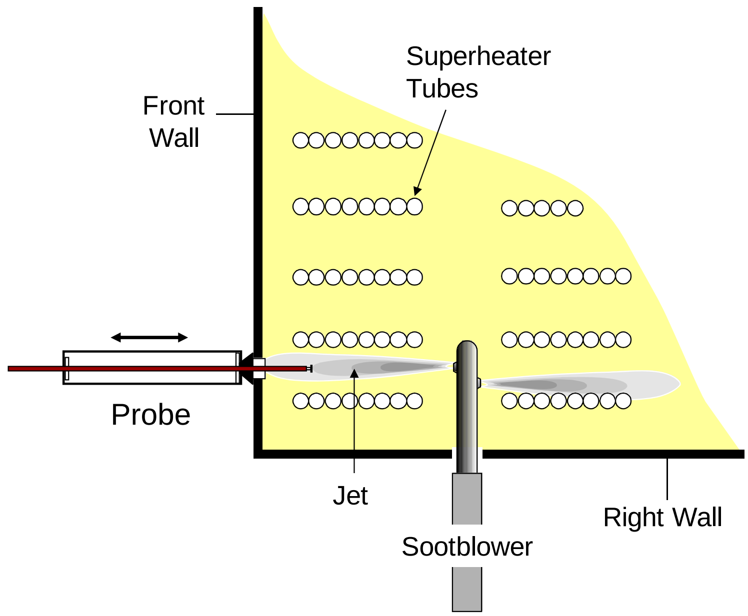

Figure 1. *Force measurement probe and sootblower locations in the boiler at Obbola.*

Probe Design and Trial Procedures

The probe system and trial procedures used in Trial 3 were essentially the same as in the previous trials [4], except that the target plates were of different sizes and shapes. As shown in Figure 2, instead of the 48 mm (1.875") diameter round target plate used in Trials 1 and 2, four square targets were used in Trial 3: a flat square target (180^o) and three arrow-shape targets with different wedge angles, 90^o, 60^o and 30^o. Although these targets had the same projected area, 48mm x 48mm (1.875" x 1.875"), they were exposed to the sootblower jet at different angles: 90^o, 130^o, 150^o and 165^o, respectively. The objective was to determine if the target shape and the jet blowing angle have any impact on the force exerted by the jet on the target.

Only the sootblower that was closest to the probe was tested. As the jet struck the target at the front end of the probe inside the boiler, it exerted a force on the target, pushing the rod against the force transducer mounted at the cold end of the probe outside the boiler. This, in turn, caused the transducer to produce a signal proportional to the jet strength. During each test, the signal was continuously monitored at high sampling rates using a data acquisition system.

The jet force was measured at three distances: 300 mm, 750 mm and 1200 mm, and at a lance pressure varying between 10 and 15 bars. One target shape was tested at a time. The target was fixed at one position, while the sootblower was operated in the usual manner with the lance rotating and moving forward and backward in the boiler, so that its opposing jets hit the target one after the other.

The recovery boiler operating condition in Trial 3 was different from that in the previous two trials. In Trial 1, the boiler had not yet been in commission, and so the tests were performed while the boiler was on oil, with the flue gas temperature at the test site varying between 100°C and 300°C. The steam for the sootblower was delivered from a hog-fuel boiler nearby. Trial 2 was performed in November 2007, two months after Trial 1. The recovery boiler was in operation but at a low liquor firing load with the flue gas temperature near the test site only 500 - 540°C. Trial 3 was conducted a year after Trial 2, with the boiler at a higher firing rate. The steam for the sootblower in both Trials 2 and 3 was taken from the recovery boiler itself.

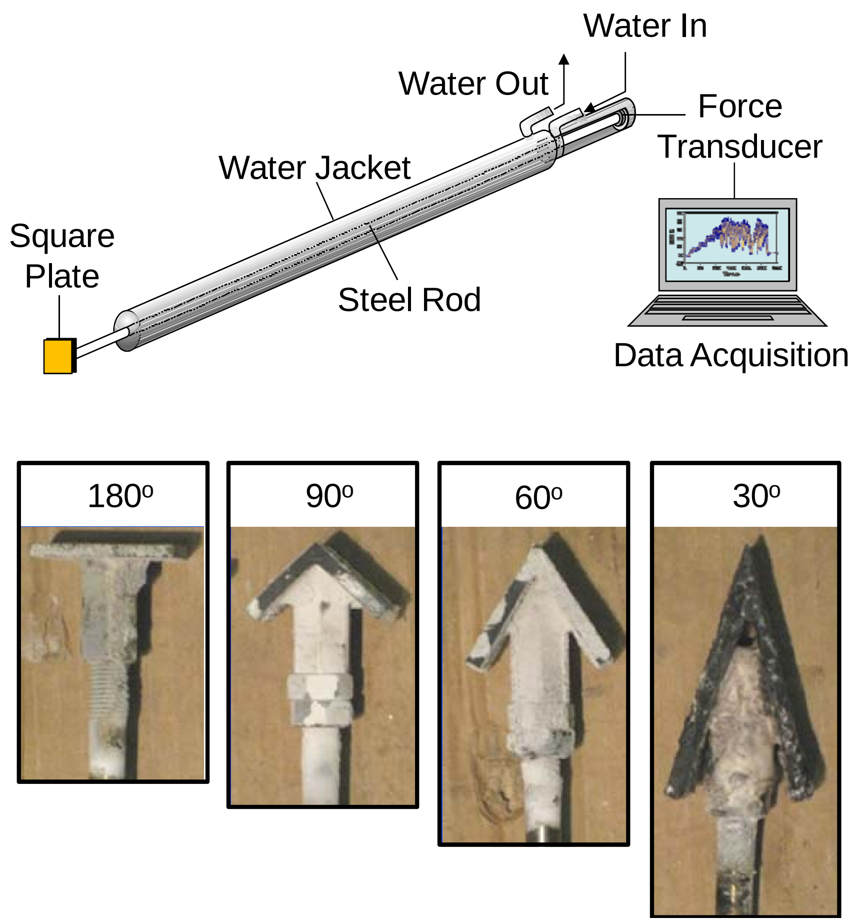

Figure 2. *Probe schematic and photos of different target shapes used in Trial 3.*

There were two main sources of errors in the jet force measurements. One was the misalignment between the jet and the probe target, and the other was the friction between the steel rod and the probe assembly. The probe must be aligned exactly along the jet axis in order to register the maximum available jet force. In Trial 1, the alignment was done while the boiler was "cold" (i.e. before it was on oil) by bringing the probe target in direct contact with the sootblower nozzle and then withdrawing it to a set distance along the jet axis [4]. Unfortunately, this method of alignment was not possible in other trials since the recovery boiler was in operation and "hot". The alignment was performed instead with the aid of a high-temperature infrared camera. The limited view of the camera, however, made the aligning procedure difficult, particularly when the probe target was placed near the sootblower nozzle, when its vibration became excessive. Repeated measurements were needed to minimize errors caused by misalignment.

The effect of friction between the rod and the probe tube was determined by turning the adjusting screw on the probe assembly back and forth. When the probe was clean, the error caused by friction was found to be within ±10

N. When the probe was covered with a layer of deposit, the friction became large, substantially reducing the force transducer signal. When this happened, the probe was taken out of the boiler, cleaned and reused.

Effect of Target Shape

Figure 3 shows the effect of target shape on jet force measured at 300 mm from the nozzle. The force decreased markedly as the target was changed from a flat plate (180^o) to various arrow shapes, despite the fact that the cross sections (projected areas) for all of these shapes were the same. The sharper the arrow wedge angle, the smaller the measured force. This is not surprising since a streamlined, elongated object tends to be aerodynamically less resistant to flow than a flat surface [7].

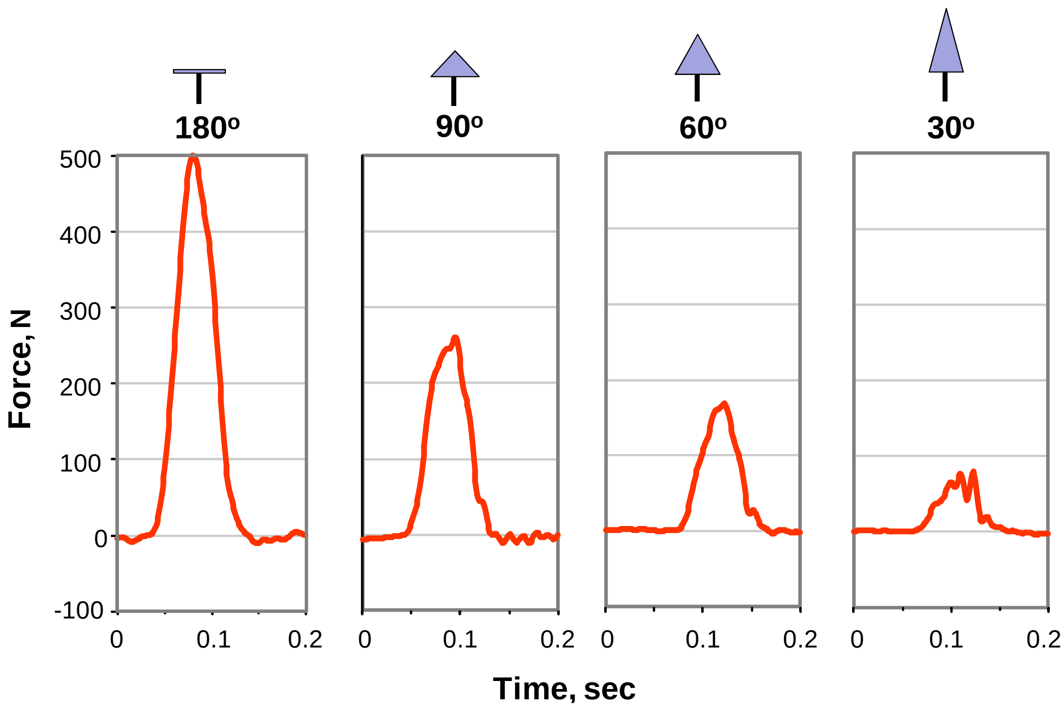

Figure 3. *Jet impacts at 300 mm, measured with different target heads.*

Figure 4 plots the jet force against target wedge angle. The relationship appears to be linear and fits well with the following equation:

$$F_\theta = \frac{\theta}{180} \times F_{max}$$

where F_θ and F_{max} are the jet force exerted on the target with a wedge angle θ and the maximum jet force exerted on a flat (180^o) plate target of the same projected area, respectively; θ is the target head angle in degrees, as shown in Figures 2 and 3. The result suggests that a flat target experiences the greatest force from a sootblower jet normal to the target surface, compared to other wedge shape targets of the same cross sectional area. Thus, a flat plate is the best target design for use in measuring the jet strength as it provides the strongest and smoothest signal possible from a sootblower jet.

Figure 5 shows the average jet force as a function of distance from the nozzle at the sootblower lance pressure of about 10 bars (9 to 11 bars). Note that in Trial 3, since the infrared inspection camera was not available, the alignment of the probe target with the sootblower jet axis was done based on records/experience obtained from the previous trials. Despite the alignment difficulty, no significant difference in results was observed. Trials 1 and 2 show practically identical results (circle markers) at a given distance, while Trial 3 shows a slightly greater force (yellow squares). The higher force value obtained for Trial 3 was likely due to the larger projected area of the square target (48 mm x 48 mm) used. Since the projected area was 28% larger than that of the round target (48 mm in diameter) used in the previous two trials, it registered a proportionally greater force. After adjusting for this larger surface area, the Trial 3 data (white squares) is in much better agreement with the data obtained from the other trials.

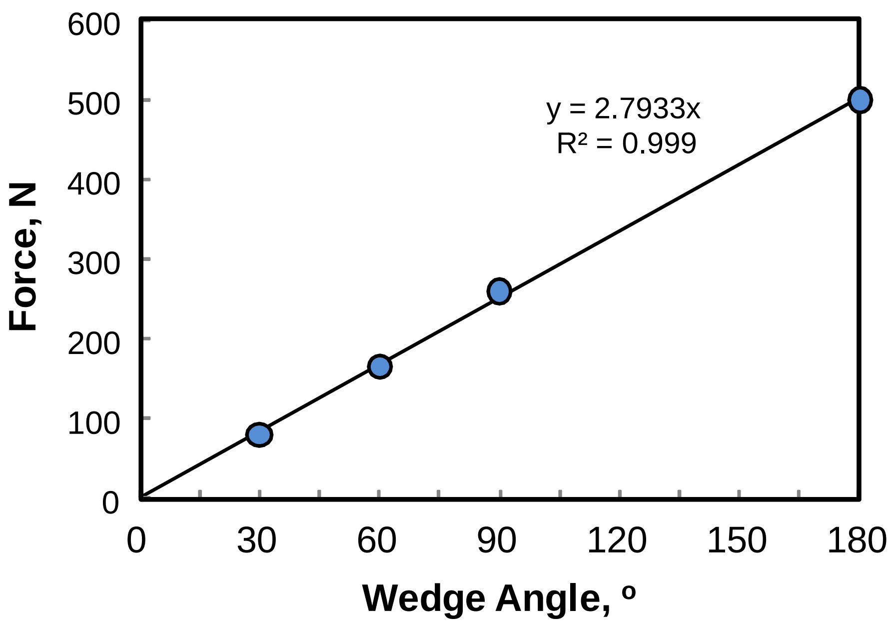

Figure 4. *Effect of wedge angle on jet impact force measured at 300 mm.*

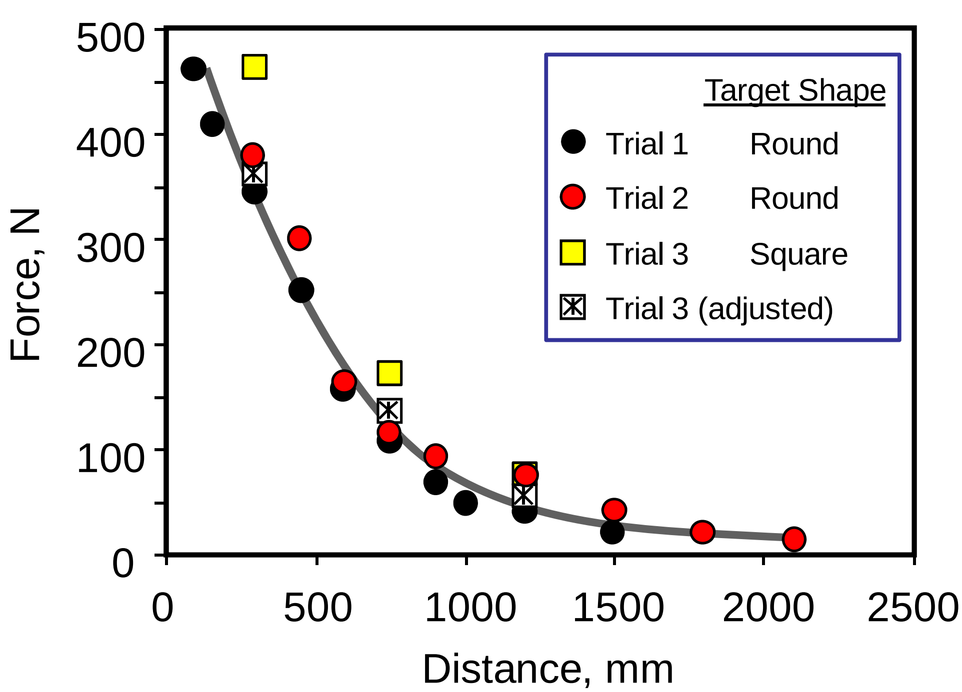

Figure 5. *Average measured force vs. distance for Trials 1, 2 and 3 at Obbola. Lance pressure: 9 to 11 bars (150 psi).*

TRIAL 4

Probe Design and Test Procedure

Trial 4 was performed at the Södra Cell Värö mill in February 2009. The recovery boiler is a larger unit than that at the Obbola mill where the first three trials took place. The front wall of this boiler was farther from the nearest sootblower in the superheater region, so that the force-measurement system used in the earlier trials could no longer be used. It was difficult to align the sootblower nozzle with the probe and to have the jet reach the probe target. As a result, the force-measurement system was redesigned for this trial.

As shown in Figure 6a, in addition to the water jacket, the probe was also cooled by air in order to protect the sensor element (force transducer) installed inside the probe at the hot end. The probe was introduced into the boiler through a manhole underneath a sootblower on a side wall of the boiler (Figure 6b). In order to change the distance between the sootblower nozzle and the probe target, three different probe geometries were used, as shown in Figure 6c. These probes allowed force measurements to be made at 300 mm, 750 mm, and 1250 mm from the sootblower nozzle.

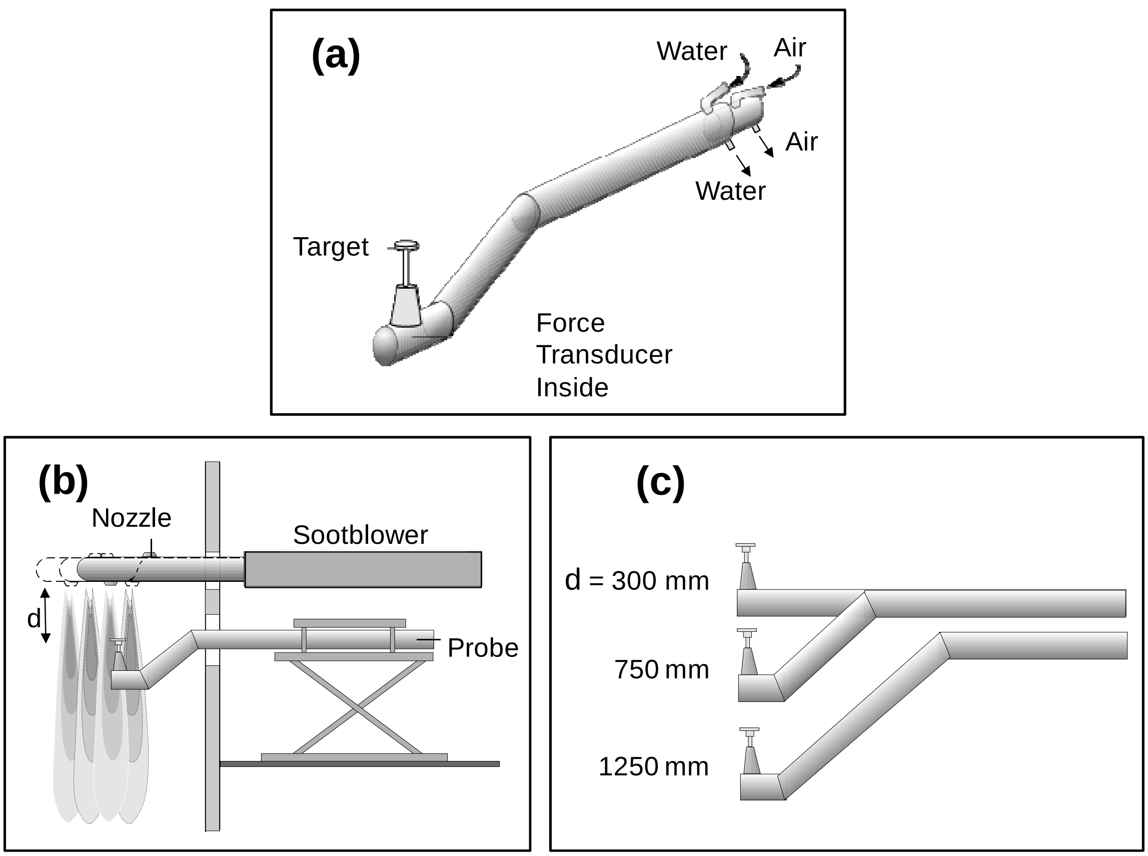

Figure 6. *Force measurement system used for Trial 4 at the Värö mill.*

A “blind” procedure was used to align the probe target with the sootblower nozzle. During alignment, the probe was inserted horizontally into the boiler in 30 mm increments. At each increment, the impact of the jet on the probe was recorded. If the target plate was located directly opposite the nozzle position at the instant of impingement, only one high amplitude impact would register (Figure 7a). If the target plate was located between two sequential positions of the nozzle, then two impacts of comparable strength would register (Figure 7b). The probe target position that yielded a single, high amplitude signal was considered to be the best alignment between sootblower nozzle and probe, and was subsequently used to measure the jet strength.

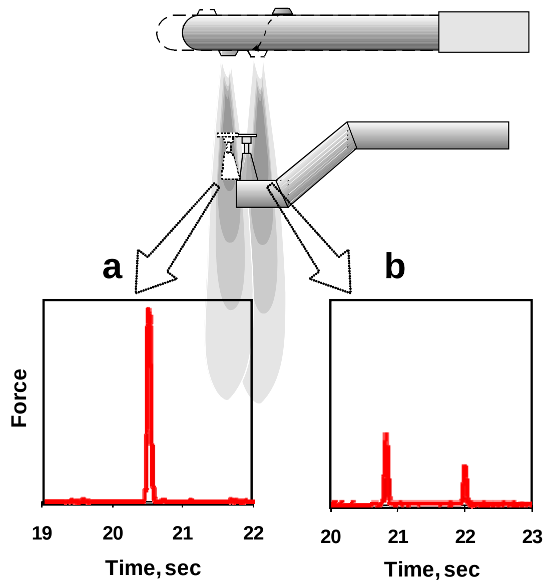

Figure 7. *Probe alignment in Trial 4. a) Good alignment resulted in a single high intensity peak; b) poor alignment resulted in two smaller peaks caused by subsequent impacts.*

Trial Results

The measurements obtained in Trial 4 with the new probe design had a better reproducibility than those obtained from the first three trials. Figure 8 shows measured jet force as a function of lance pressure for three distances from the nozzle: 300 mm, 750 mm and 1250 mm. The blank markers represent Trial 3 data while the solid markers represent Trial 4 data. Note that since no measurements were taken at 1250 mm in Trial 3, data at 1200 mm is plotted instead. Both trials show similar results (although the data for Trial 4 appears to be less scattered), confirming that the force produced by a sootblower jet increases almost linearly with an increase in lance pressure.

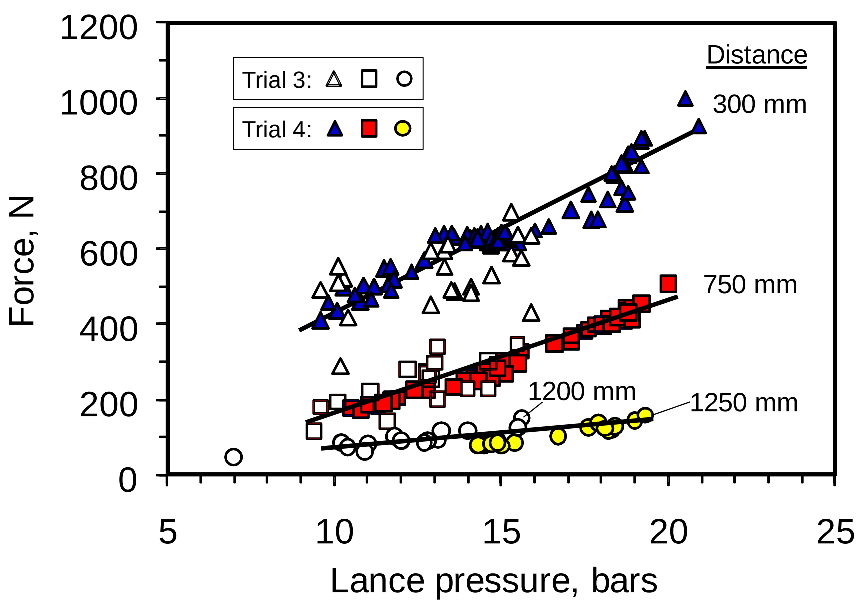

Figure 8. *Jet force as a function of lance pressure and distance from the nozzle (the blank markers are data from Trial 3; solid markers are data from Trial 4).*

CONCLUSIONS

The results obtained confirm the findings of the previous trials, showing that at a given distance, the force produced by sootblower jet increases almost linearly with an increase in lance pressure. At a given lance pressure, the jet force decreases rapidly as the distance increases, retaining less than 10% of its original strength at a distance of 1 m (3 ft) from the nozzle. The results also show that the exerted force is directly proportional to the projected area of the target. It is highest when the target is flat, and increases linearly with an increase in wedge angle of the target.

These field data on sootblower jet strength are very valuable, allowing us to validate the sootblower jet turbulence model that has been developed in our laboratory, and to use the validated model to predict sootblower jet strength in recovery boilers.

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Measurements of Sootblower Jet Strength in Kraft Recovery Boilers – Part II:

Results of the 3rd and 4th field trials

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TAPPI PEERS Conference
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Dedication

This work is dedicated to Kari Saviharju of Andritz who initiated the project and helped bring it to fruition.

Mr. Saviharju died of cancer in December 2008

Background

- Sootblowers are used to remove deposits from tube surfaces; as such they are of vital importance to recovery boiler operations
- Much work has been done to examine jet characteristics and interaction with tubes
  - Performed under controlled laboratory conditions using small scale equipment
  - Through analytical/numerical modeling
- Theoretical, experimental and modeling results have not been validated

Background

- A collaborative project was initiated by Andritz to examine sootblower performance in-situ
- Work involved:
  - Design and construction of two force-measurement systems
  - Four 4 field trials at two kraft pulp mills
  - Data analysis
  - Validation of the SJT sootblower jet model
- The first to systematically examine sootblower performance in-situ

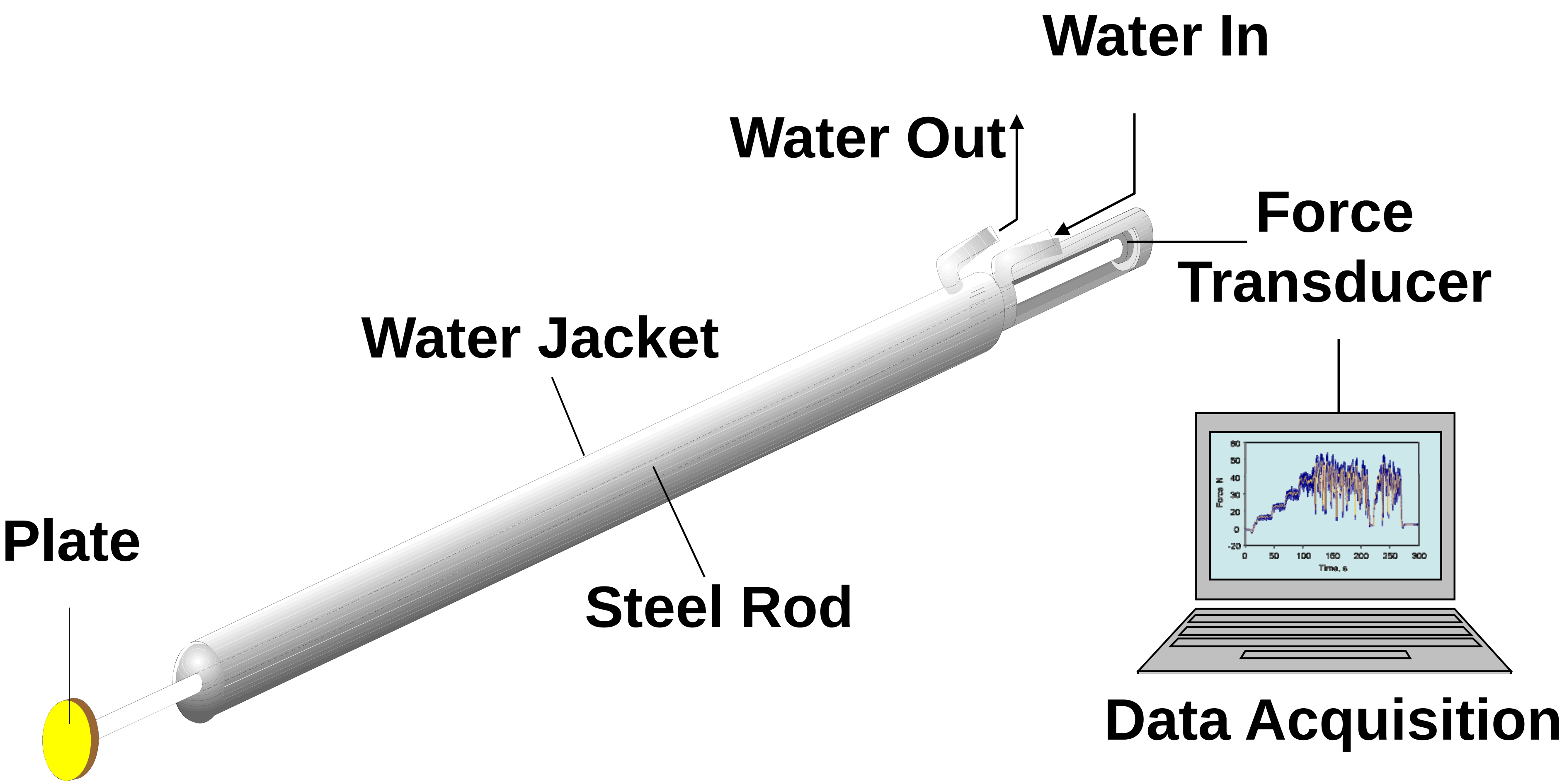
Background

- **Part I of this work**
  - **Trials 1 and 2 at a pulp mill in Obbola, Sweden**
  - **Results presented at the ICRC 2010**
  - **Published in TAPPI Journal, February 2011**
- **This presentation concerns Trials 3 and 4**
  - **Trial 3: Obbola mill**
  - **Trial 4: Värö mill**
  - **Effects of different parameters were examined**

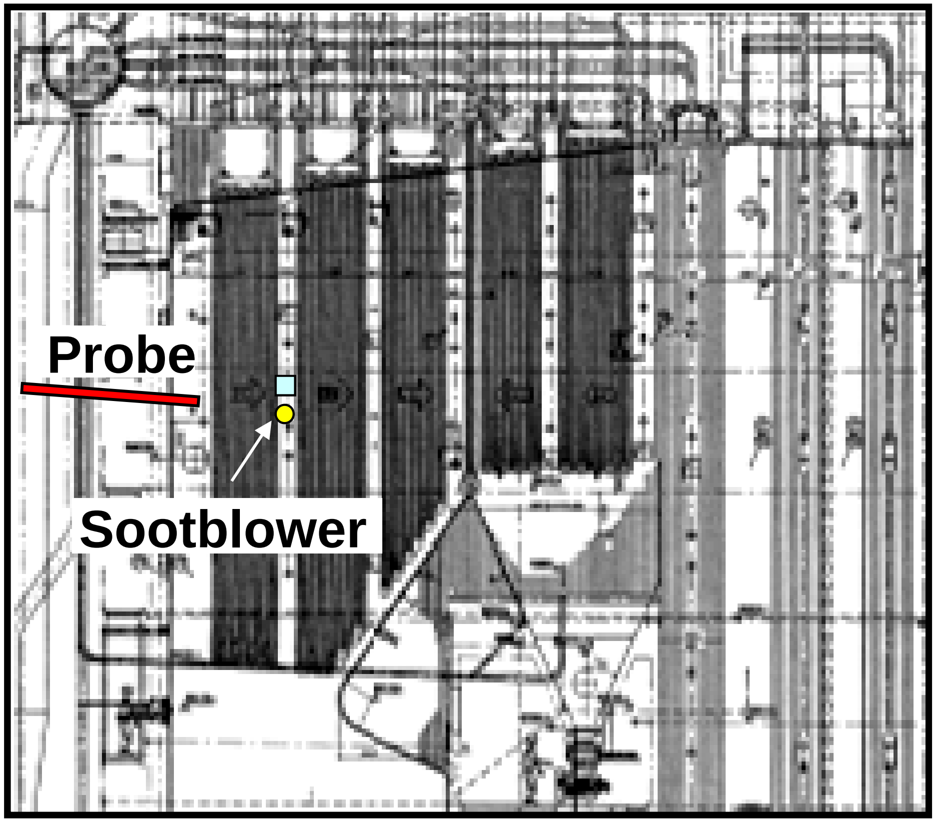
This Presentation

- Force Measurement Probes
- Brief Summary of Trial 1 and Trial 2 Results
- Trial 3 and Trial 4 Test Procedures
- Results
- Summary and Conclusions

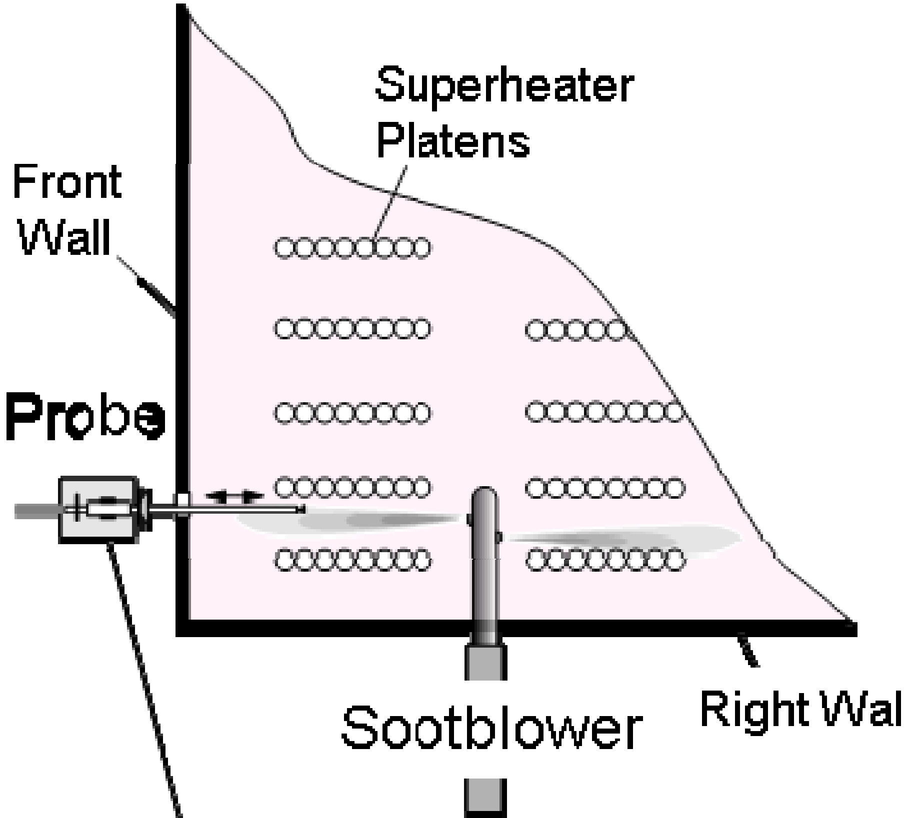
In-situ Jet Force Measurements



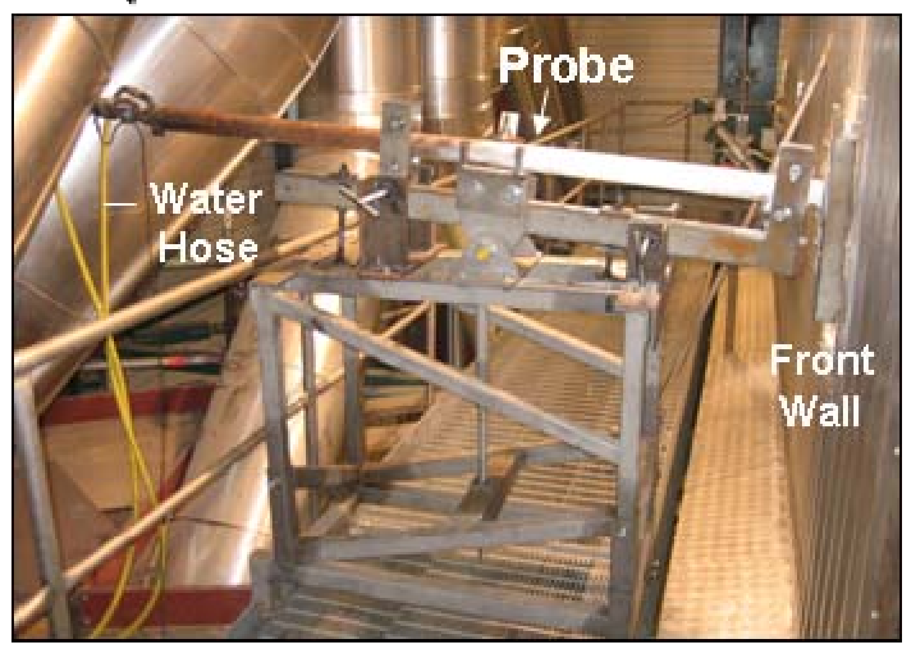
Test Site



Probe
Sootblower



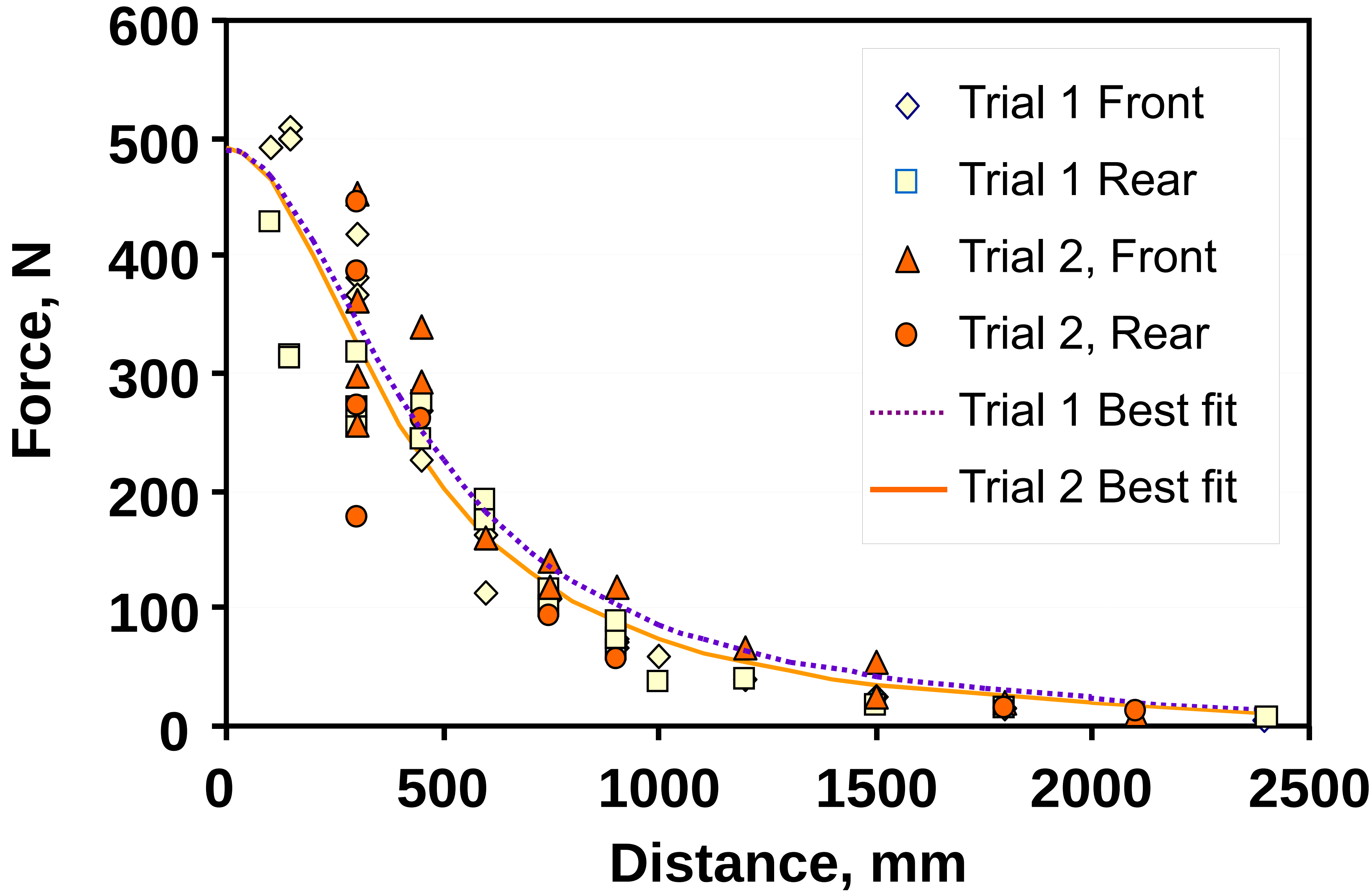
Superheater Platens
Front Wall
Probe
Sootblower
Right Wall



Probe
Water Hose
Front Wall

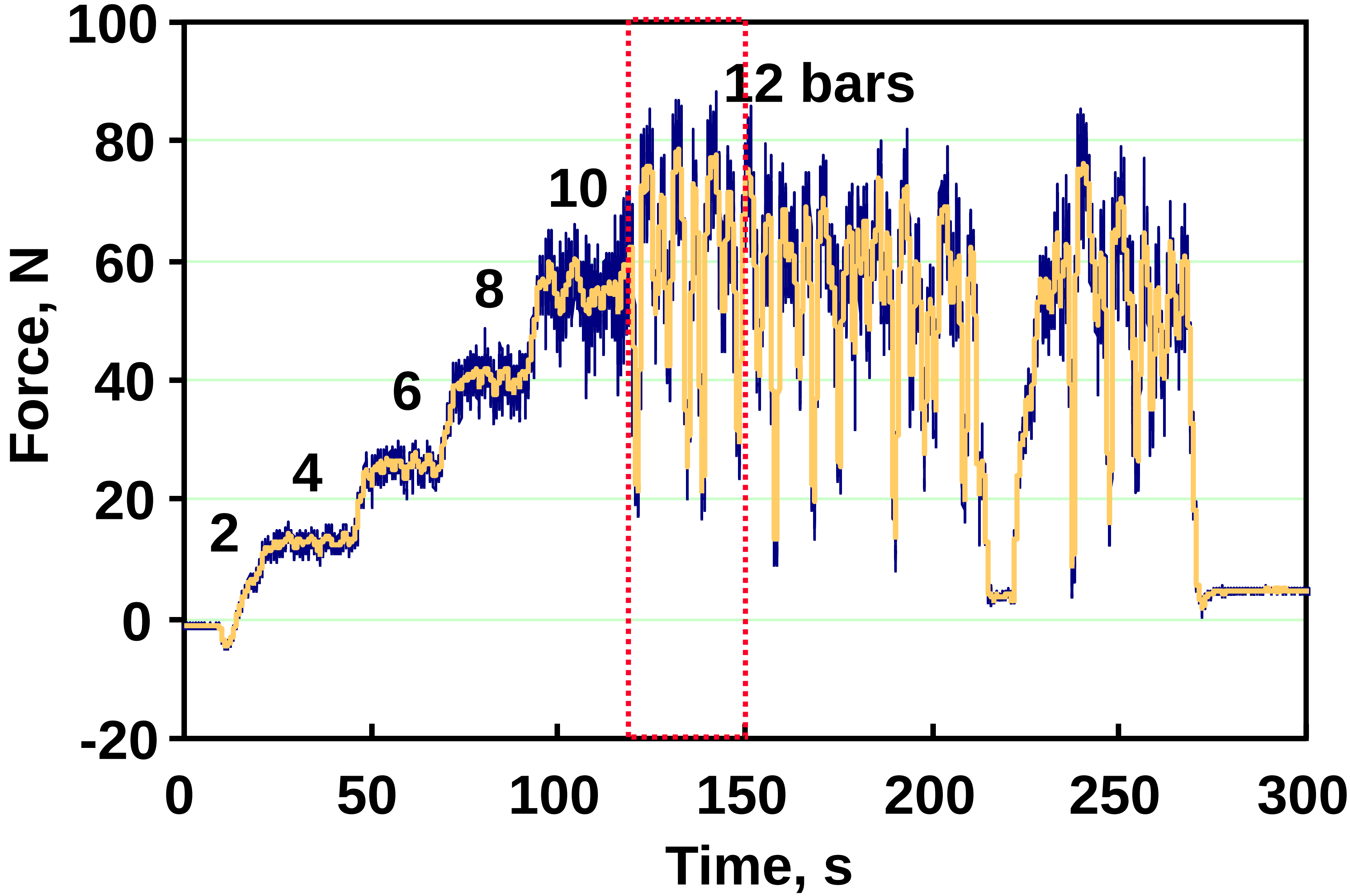
Trials 1 and 2 Result Comparison

Running Sootblowing Tests, Lance Pressure = 10 bars



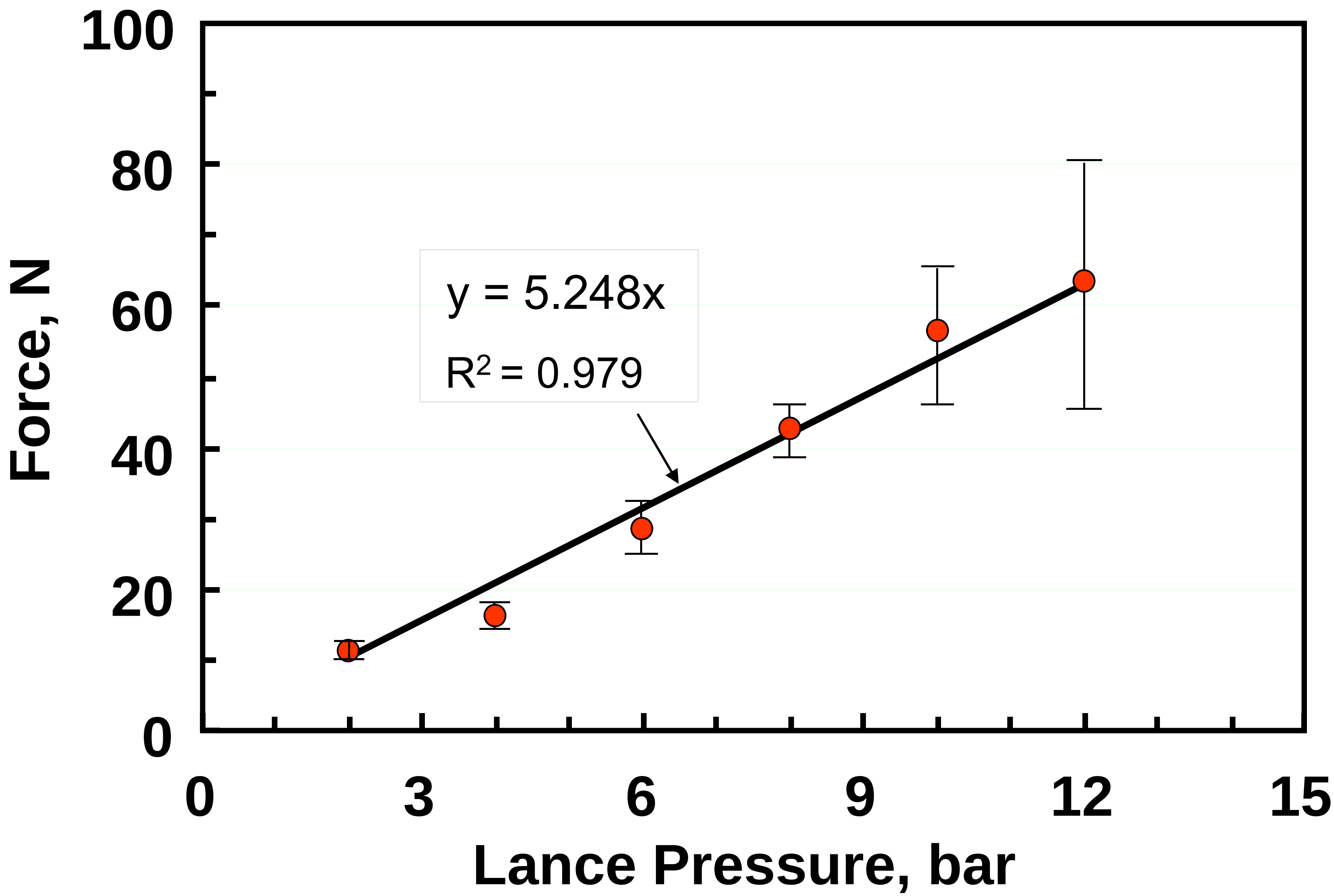
Force Measured at 750 mm

During a Stationary Sootblowing Test



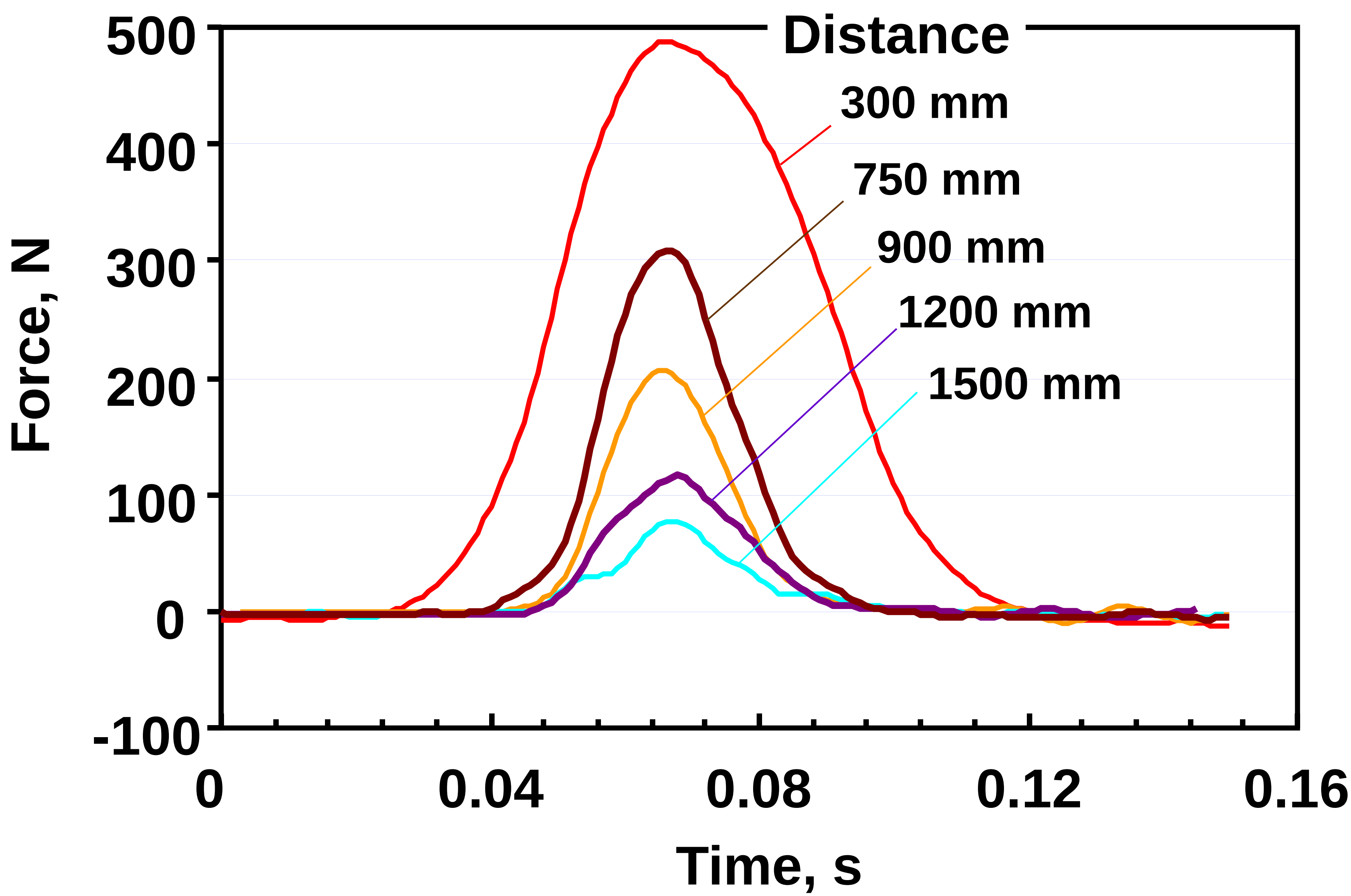
Effect of Lance Pressure

(Stationary Sootblowing Test at 750 mm)

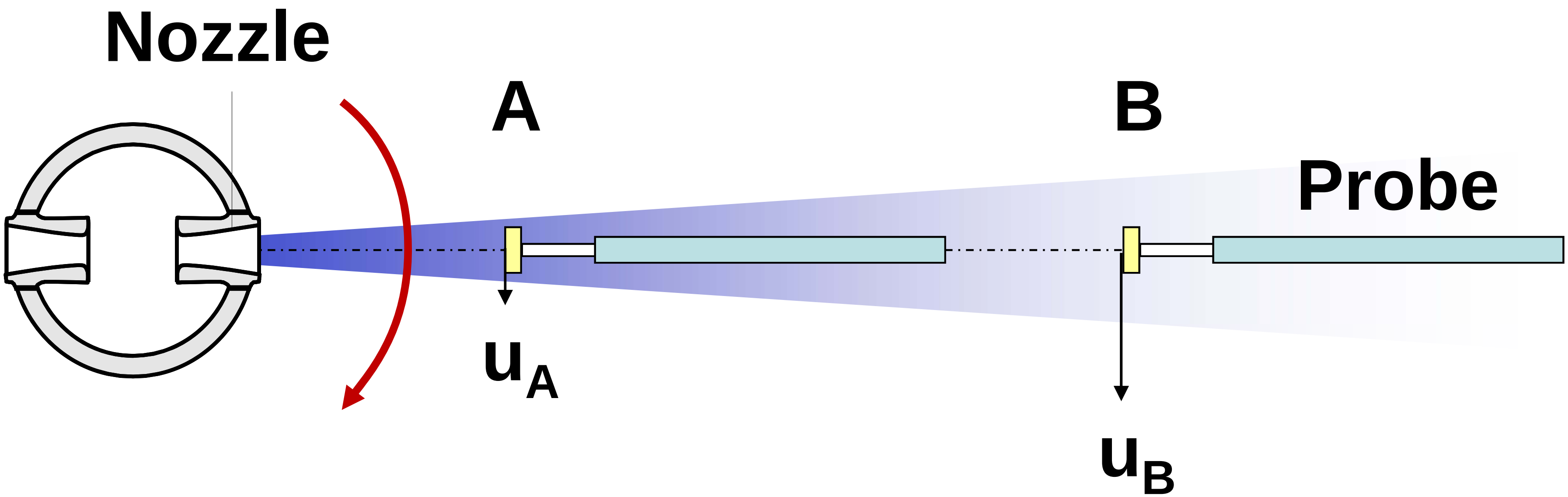


Force Profile vs. Distance

Lance Pressure = 16~18 bars



Force Profile vs. Distance



u: Jet tangential velocity

$u_A < u_B$

Trial 3

- Same boiler as Trials 1 and 2
- Same procedures
  - Boiler was on full load
  - Various target shapes were used

Various Target Shapes

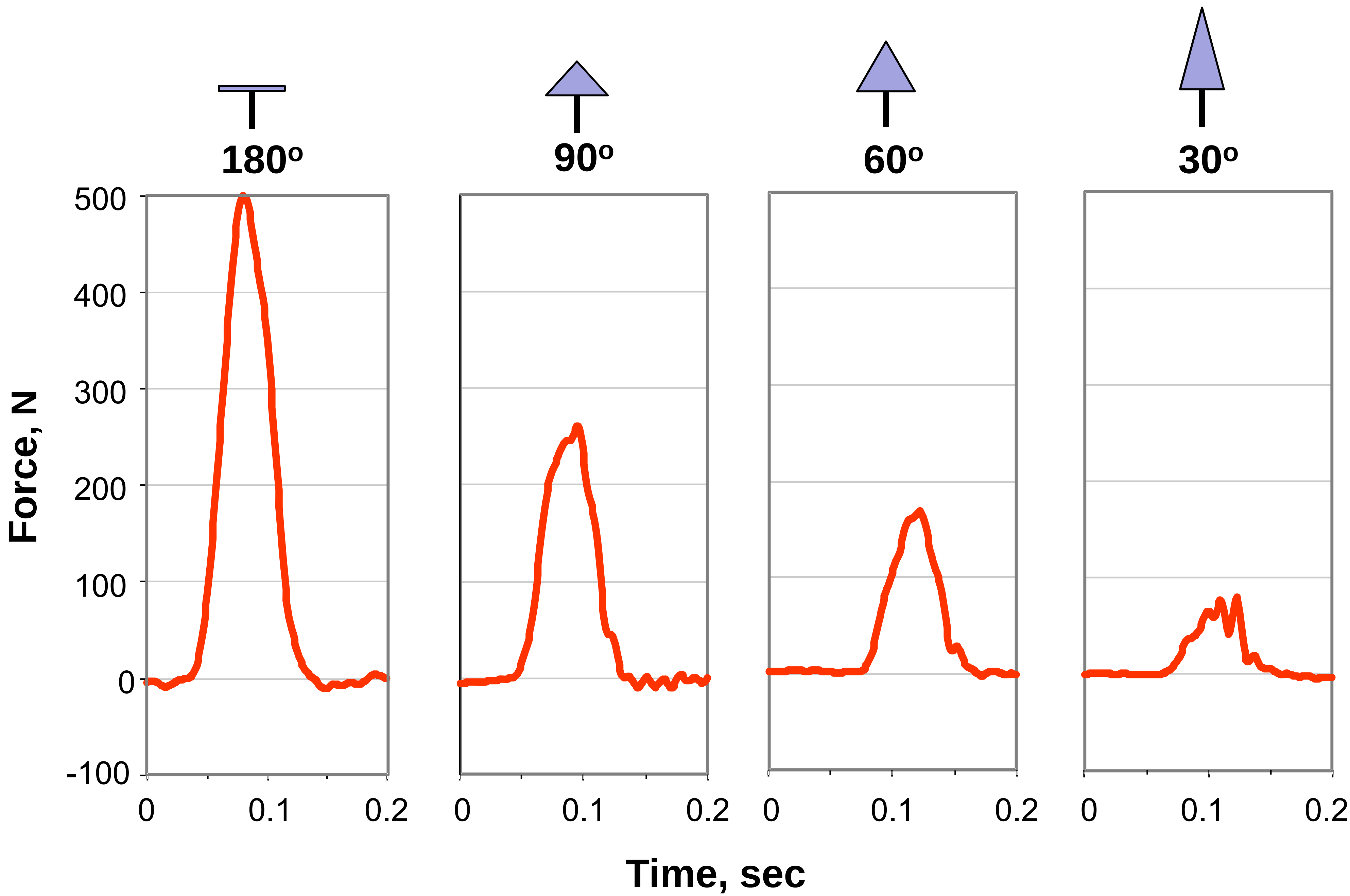
180°

90°

60°

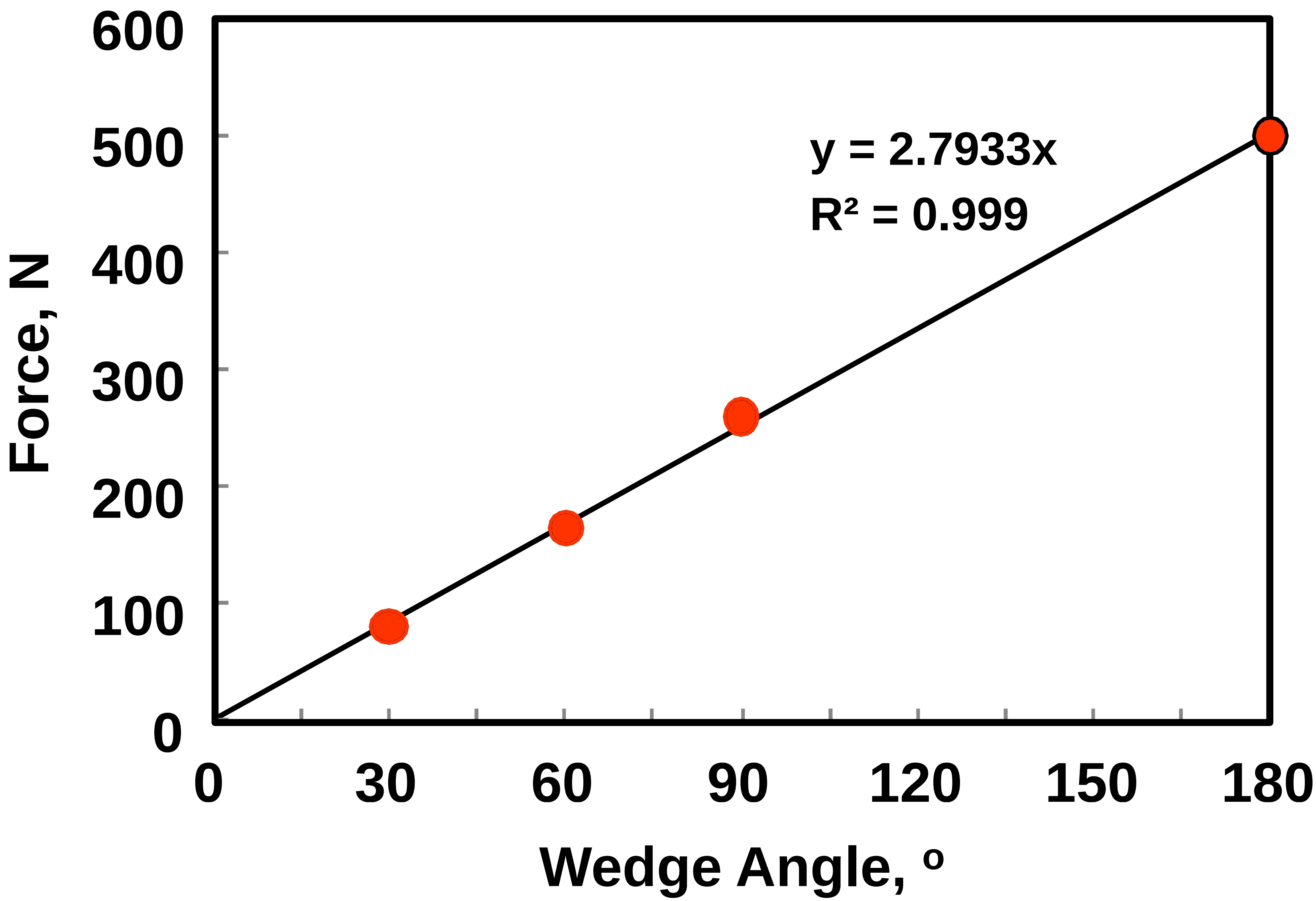
30°

Force Exerted on Probe Heads at 300 mm

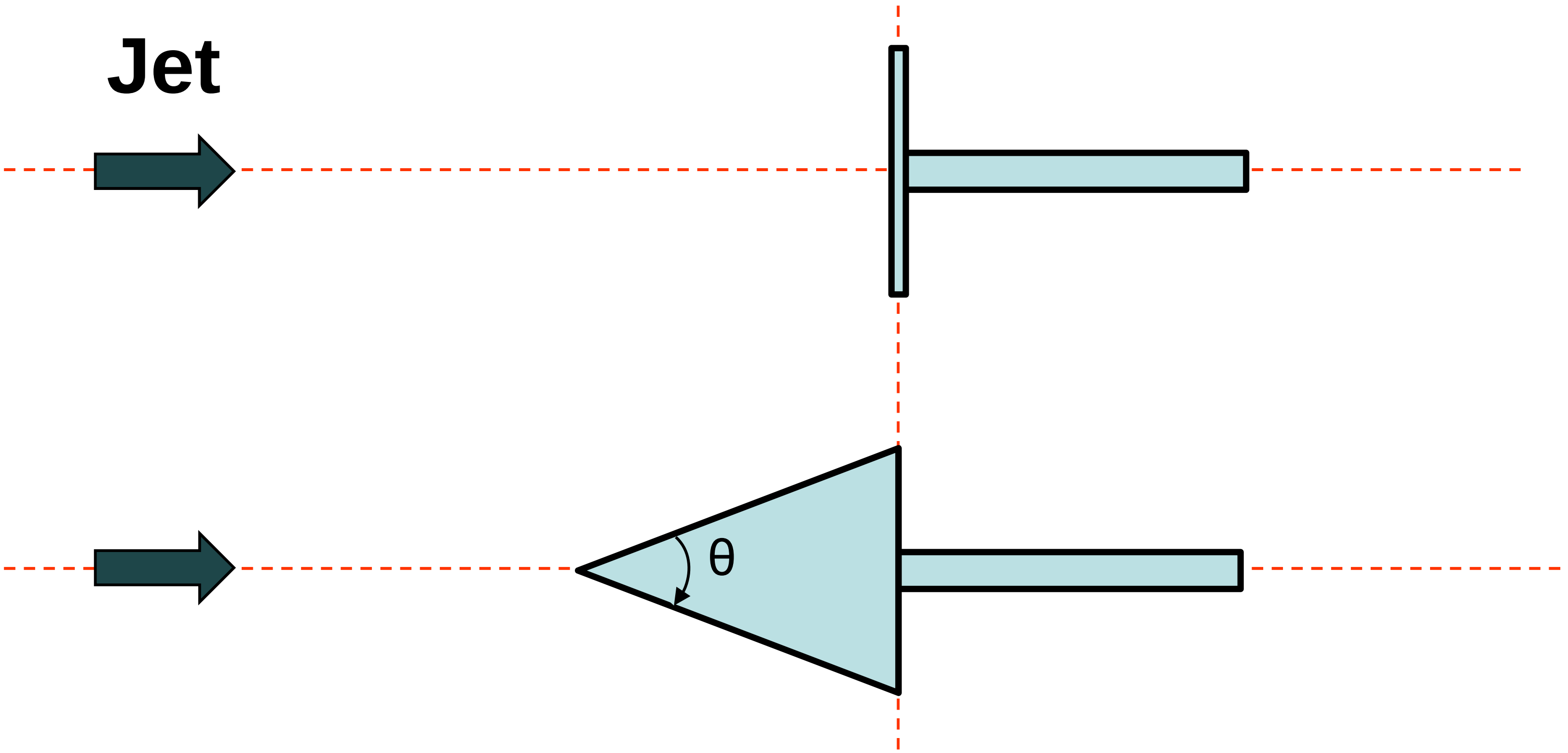


Force vs. Wedge Angle

(Distance = 300 mm)

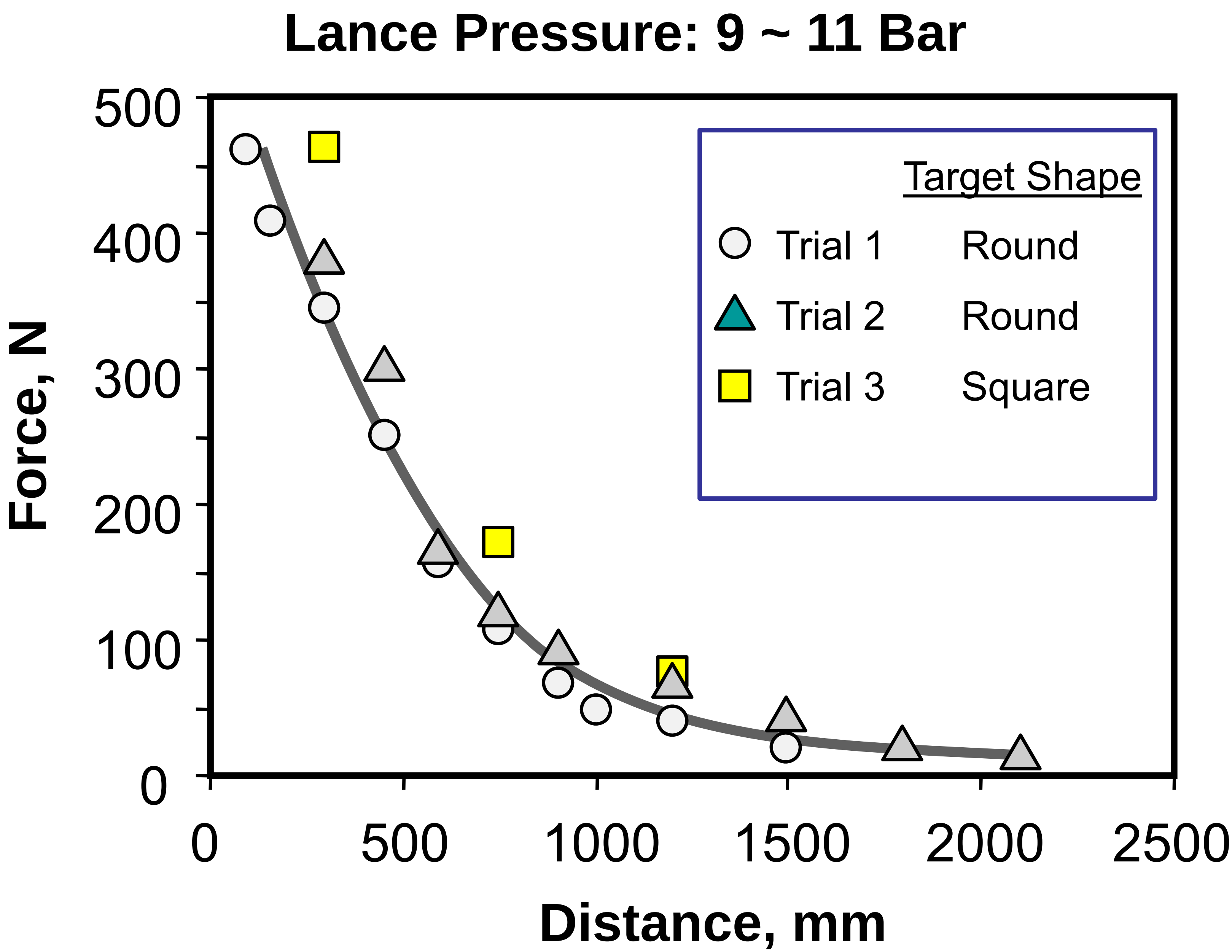


Force on Wedge Angle

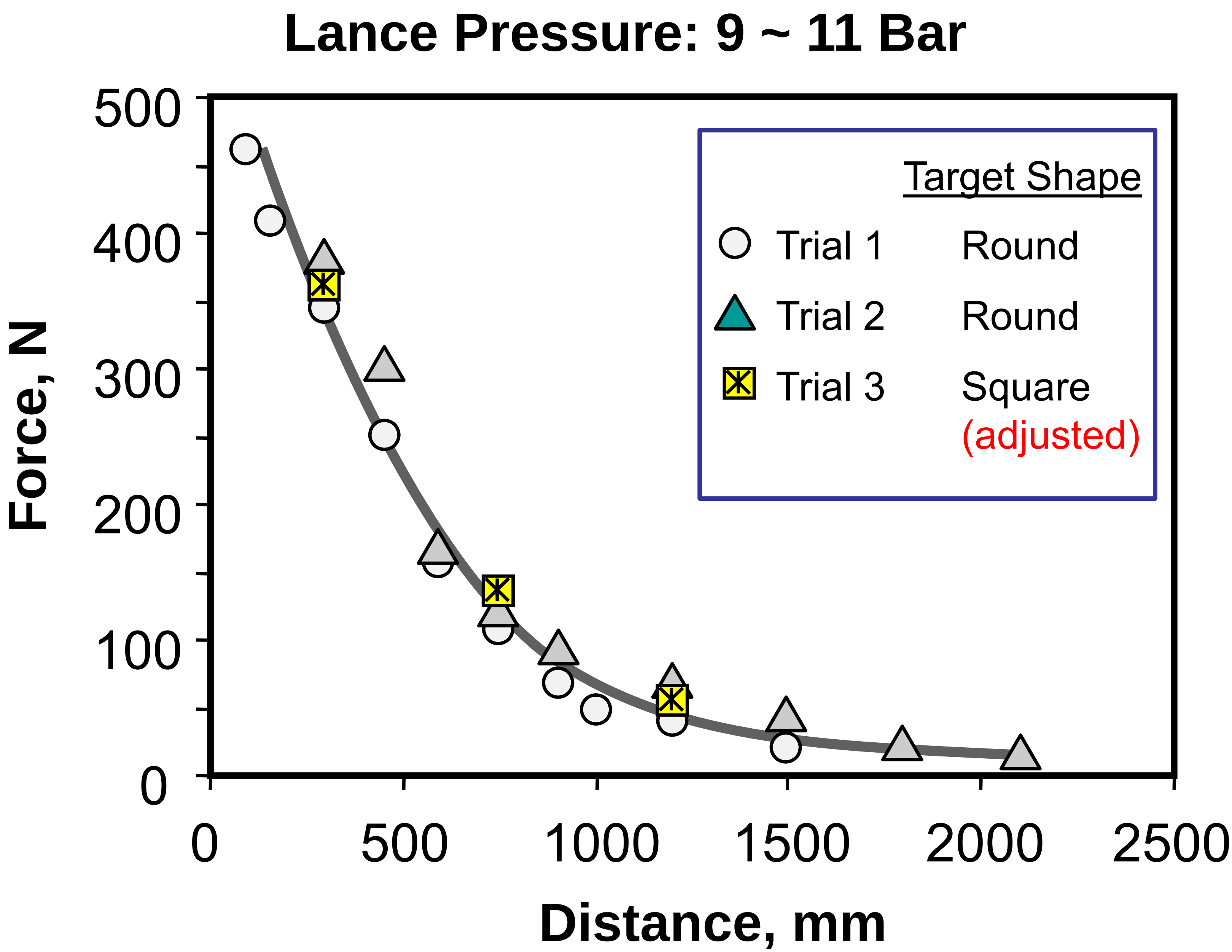


$$F_\theta = \frac{\theta}{180} F_{180}$$

Effect of Target Shape



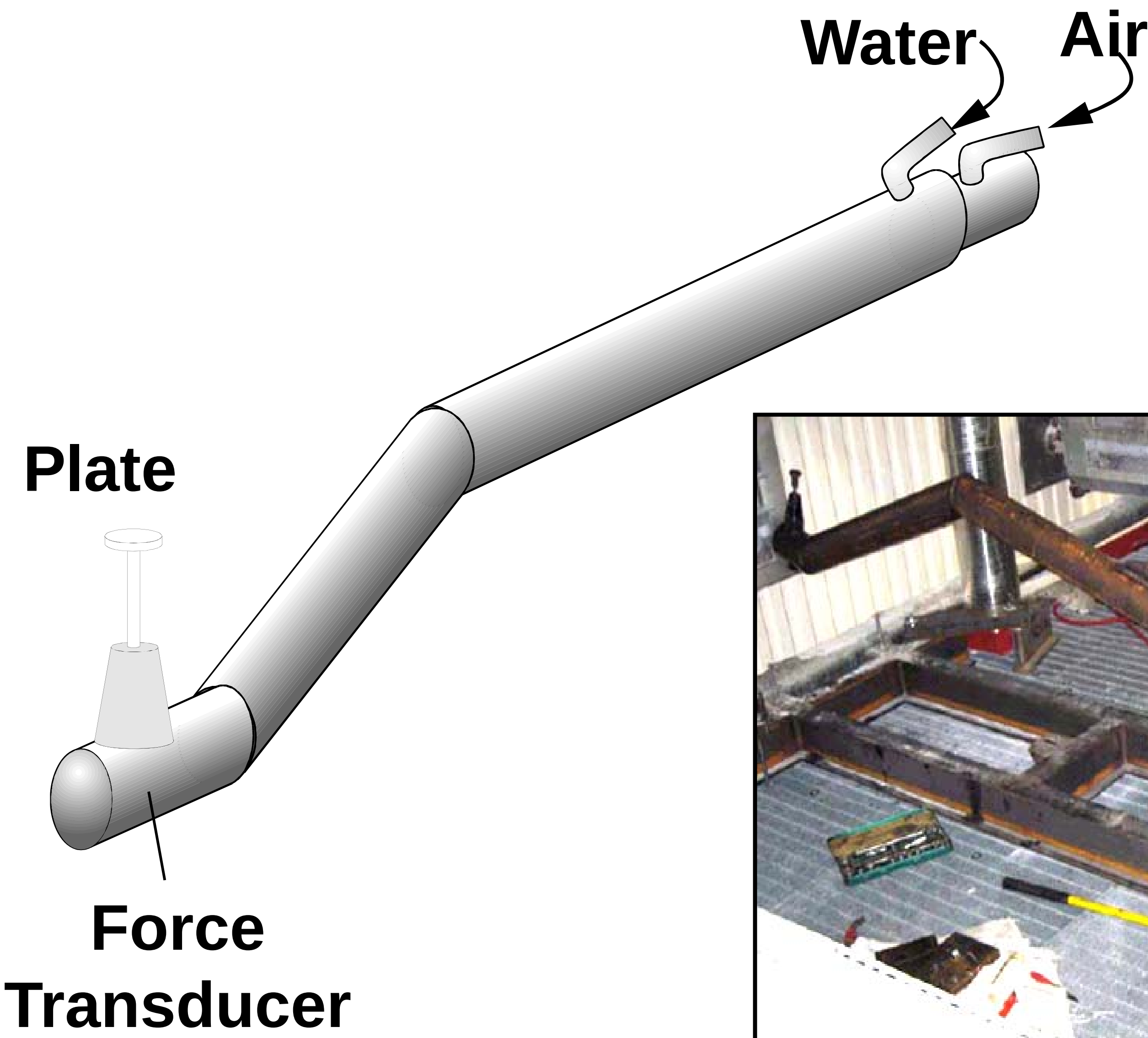
Effect of Target Shape

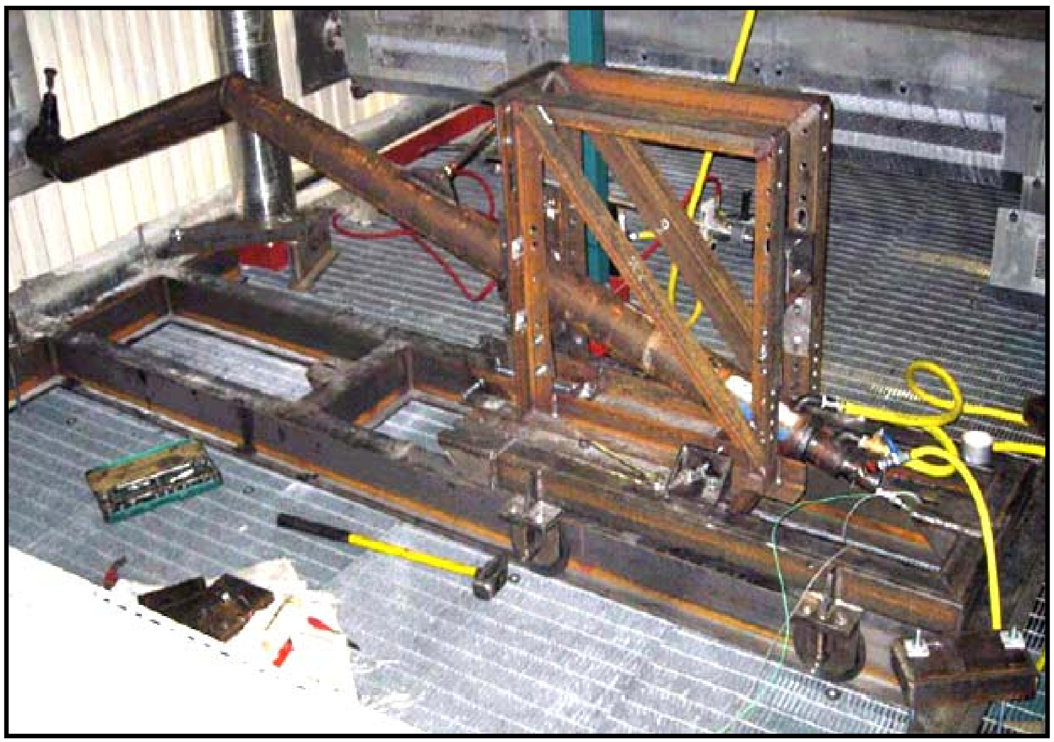


Trial 4

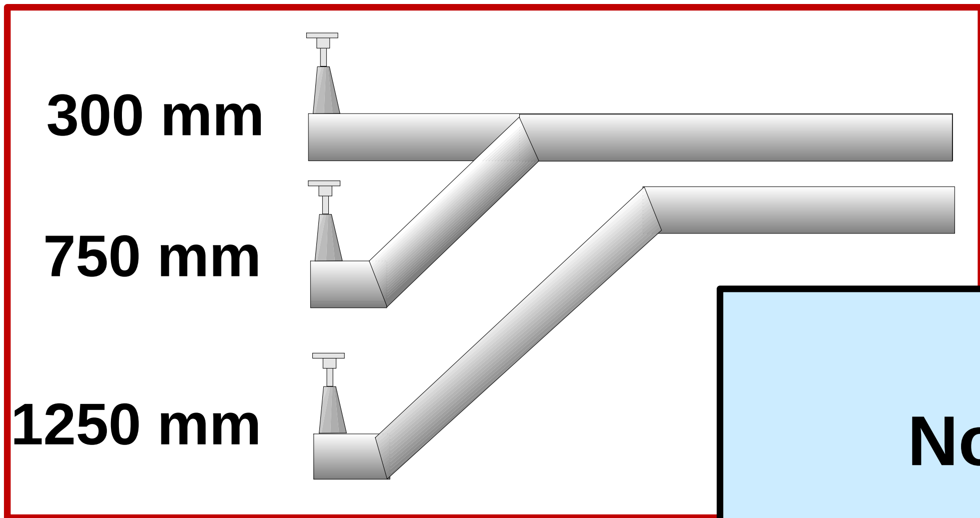
- Värö mill, larger recovery boiler
- Distance between from front wall and SH entrance: too long to use the Obbola probe
- A different probe design was used
  - Installed on a sidewall underneath a sootblower
  - 3 fixed distances
  - One probe at each distance

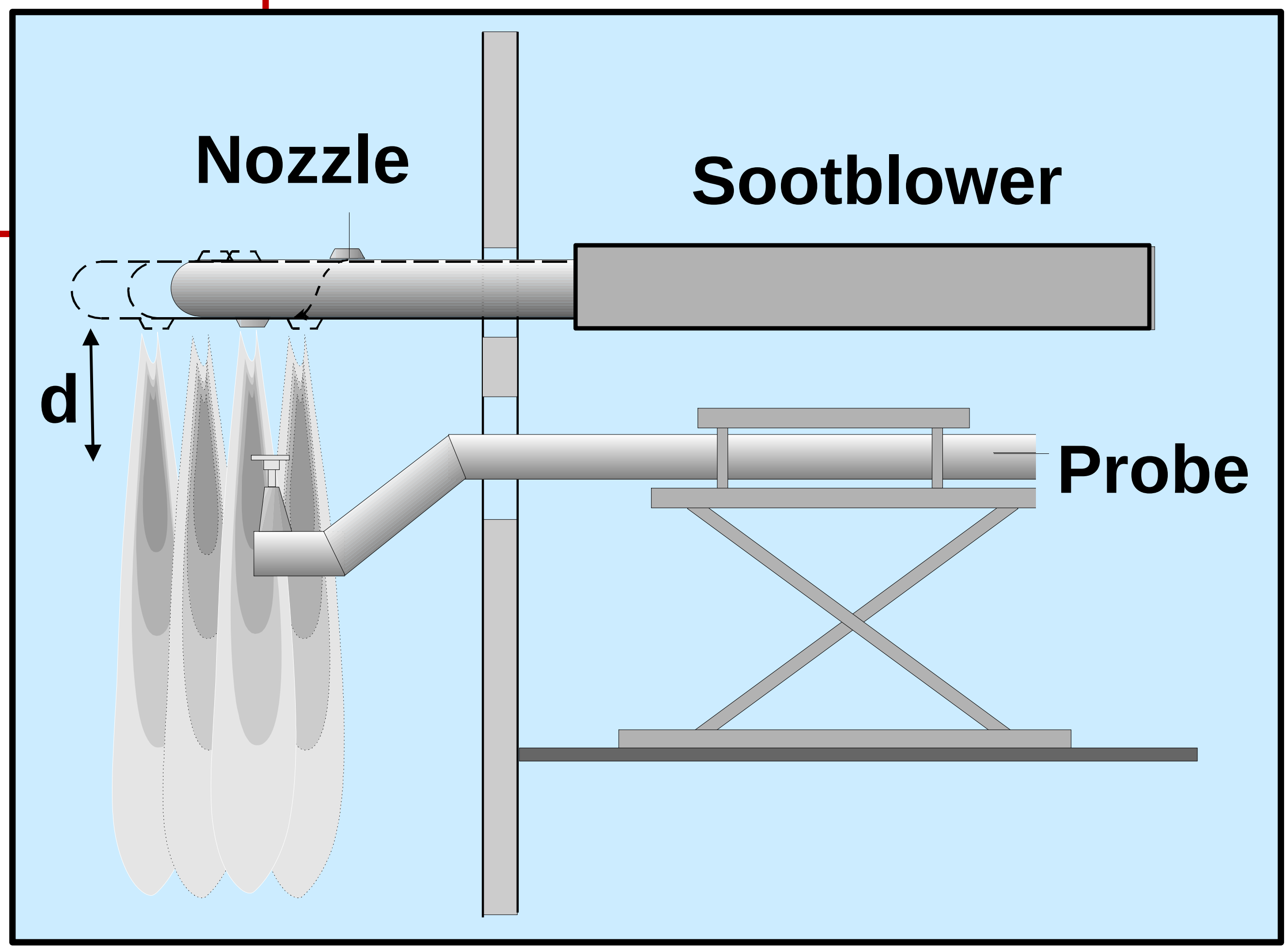
Trial 4 Force Measurement Probe



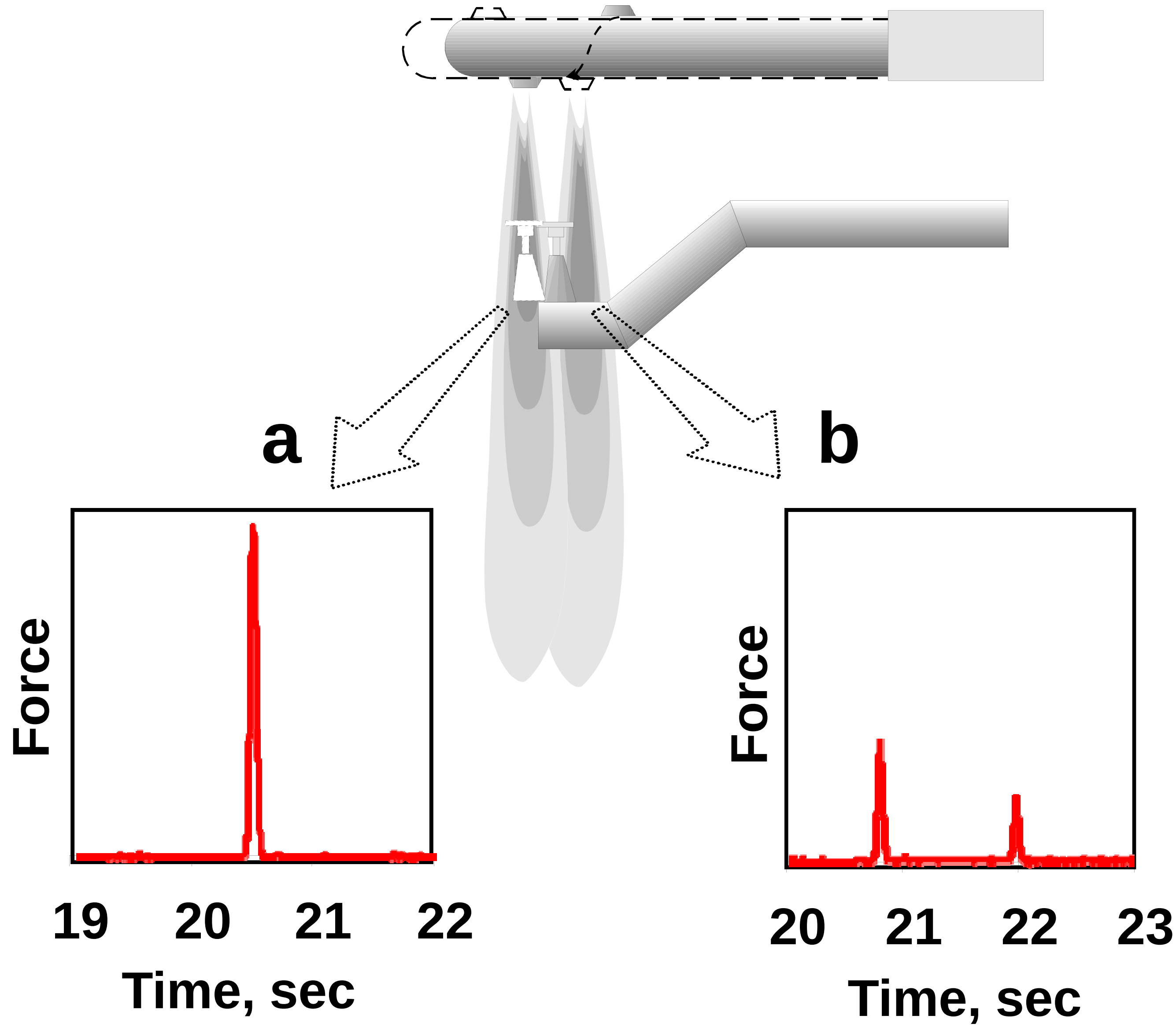


Trial 4 Force Measurement Probe

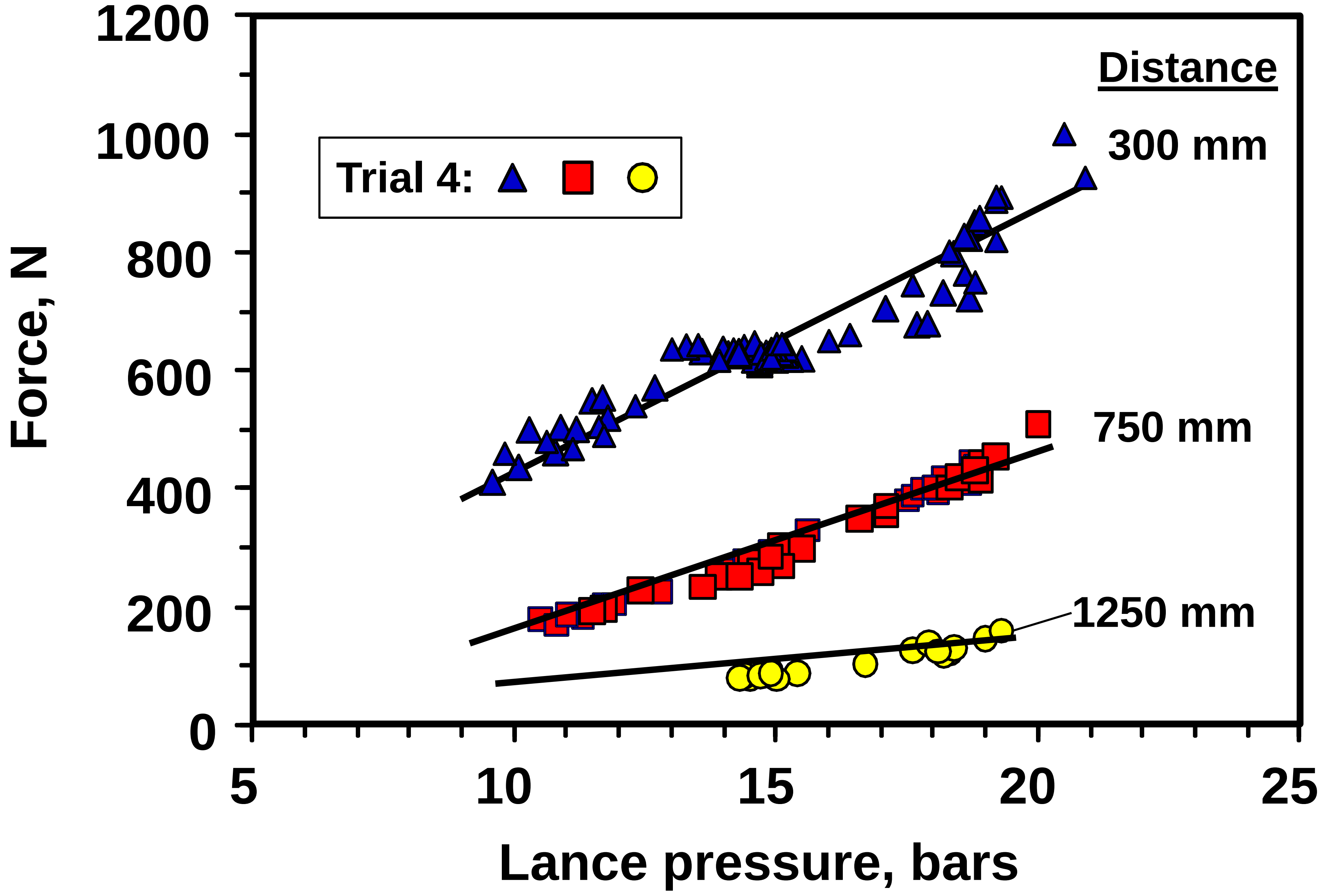




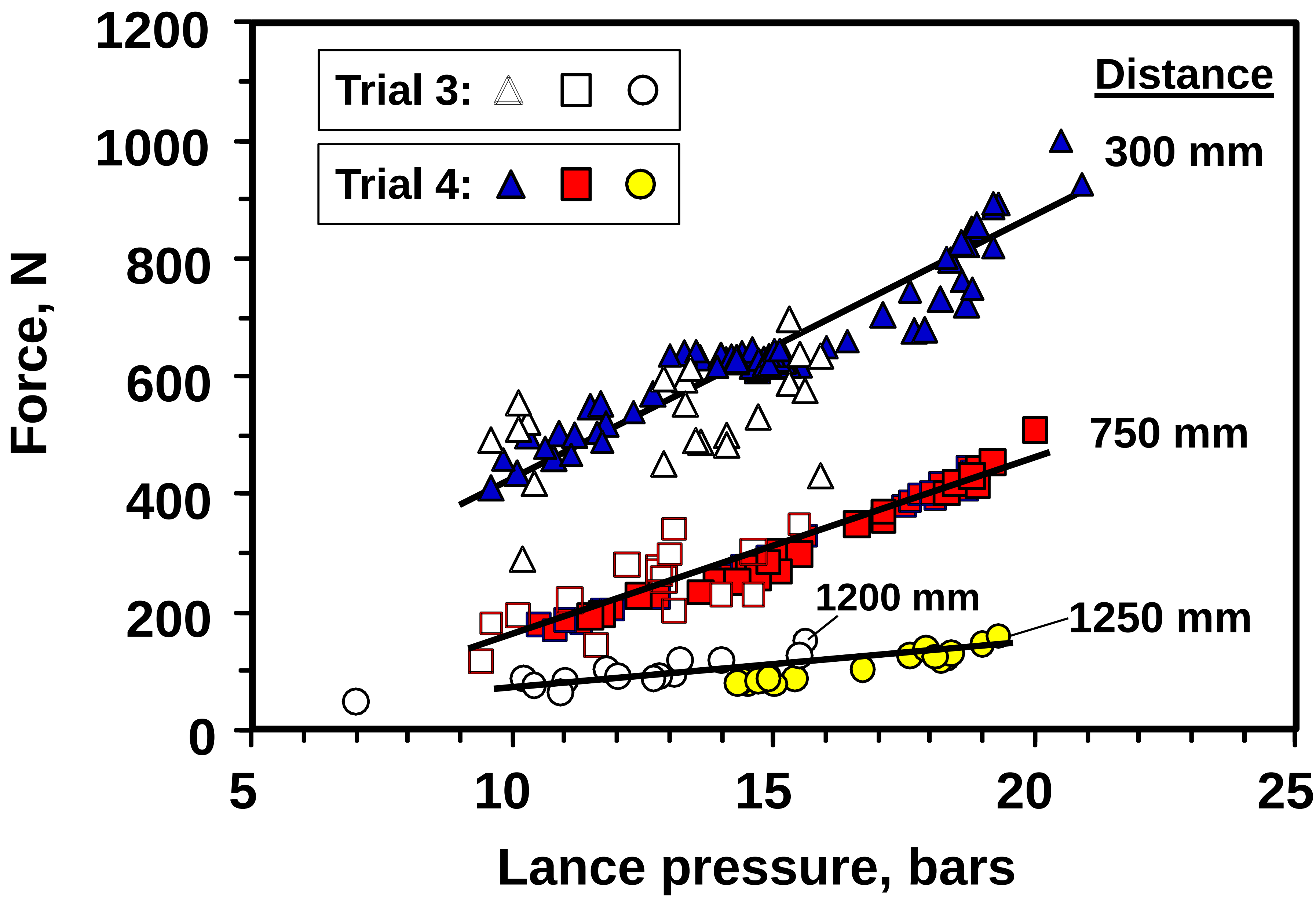
Probe Alignment



Trial 4 Results



Result Comparison (Trials 3 & 4)



Summary

- Two additional field studies were conducted in different recovery boilers in Sweden
- The results confirm the findings of previous trials

Conclusions

- At a given distance, the force exerted on a target by a fully expanded sootblower jet increases nearly linearly with an increase in lance pressure
- At a given lance pressure, the jet force decreases drastically as the distance between the sootblower nozzle and the target increases.
  - At 1 m (3 ft) from the nozzle, the jet retains less than 10% of its original strength.

Conclusions

- Targets of different sizes and shapes receive different jet forces
- A flat surface receives a greater force from the jet than an inclined surface with the same projected area
- Results were also consistent with those obtained from laboratory studies and numerical simulations

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  - Babcock & Wilcox
  - Boise Paper
  - Carter Holt Harvey
  - Celulose Nipo-Brasileira
  - Clyde-Bergemann
  - DMI Peace River Pulp
  - Fibria
  - International Paper
  - Irving Pulp & Paper
  - Metso Power
  - MeadWestvaco
  - StoraEnso Research
  - Tembec.