A High Efficiency Inertial CO_2 Extraction System — ICES

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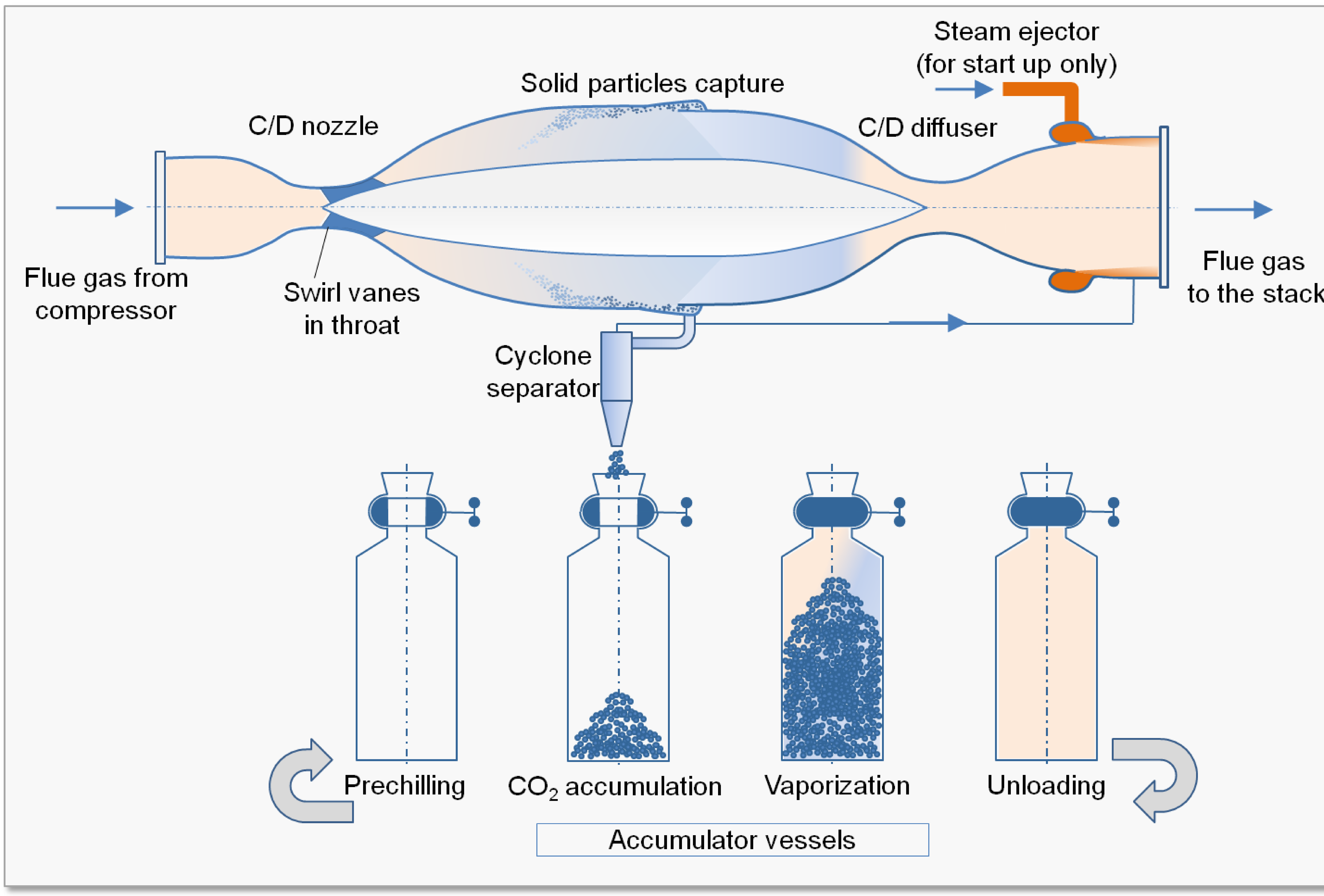


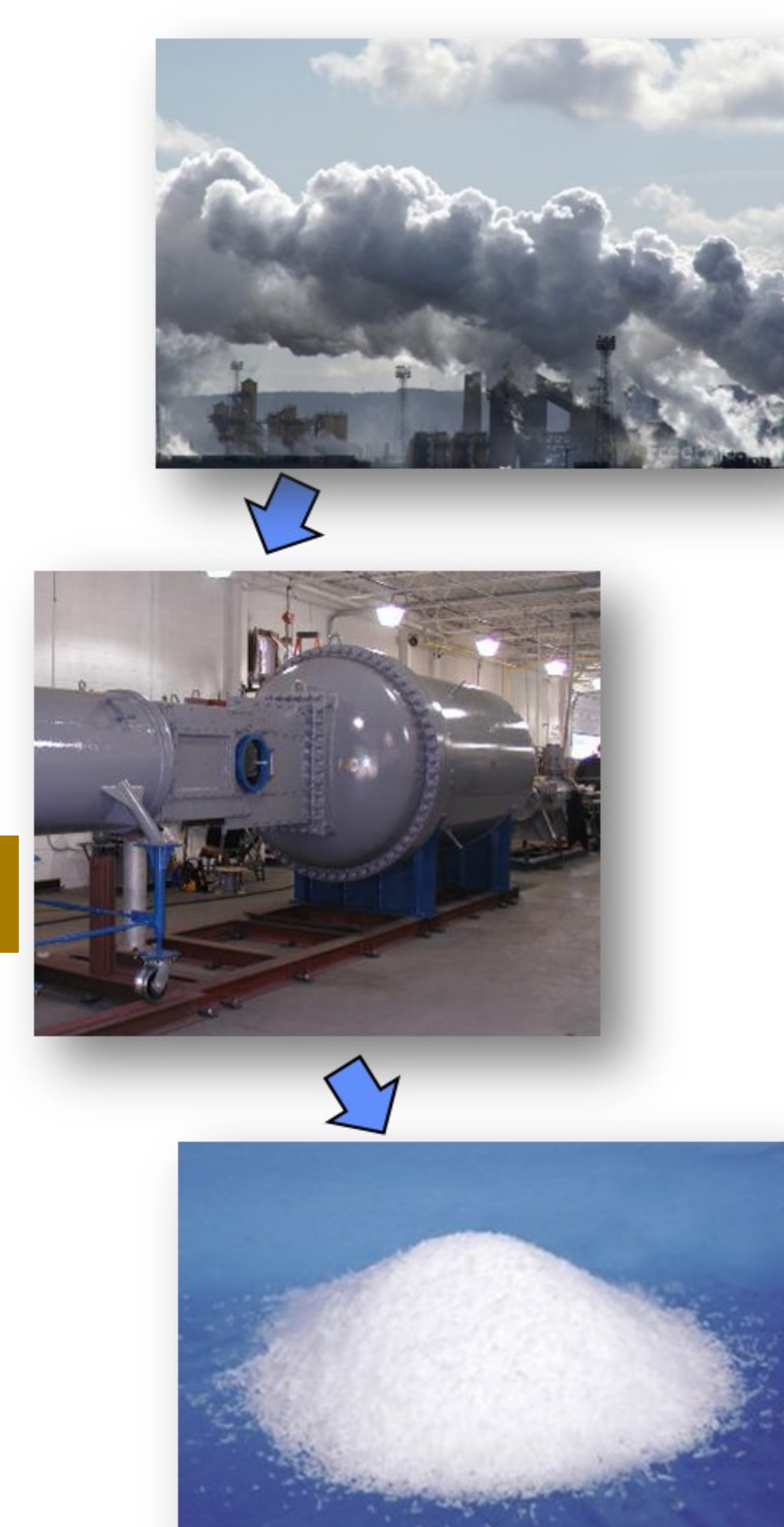
ICES Concept

- Pulverized coal power plant flue gas contains ~15% CO_2 in gaseous form at low pressure
- In ICES we compress flue gas to a moderate level and use the low temperature created by supersonic expansion to freeze the CO_2 in the flow
- ICES uses swirl induced in the flow to centrifugally separate the solid particles like a supersonic cyclone
- We capture and collect the CO_2 (as dry ice) and then process using a self-pressurization system exploiting power plant waste heat

Unique/Transformational Characteristics

- Simple, inexpensive construction with no moving parts
- Benign operating conditions
- No chemical additives required
- No membranes or adsorbents to replace
- Passive operation requires only flue gas compression and momentary plant steam divert to start process
- Projected to consume slightly more than half the energy of the baseline amine scrubber

Technical Background



- Derived from aerospace wind tunnel applications where water and carbon dioxide are known to condense/freeze in supersonic air flow
- Leverages ATK wind tunnel experience and ACEnT Laboratories Phase 1 SBIR from the Department of Energy for hydrogen separation from coal gasification plants
- Supersonic swirl separators have been employed successfully for gas dehydration – increasing speed to near hypersonic (5 times the speed of sound) is a key challenge
- Capture, collection and self-pressurization of solid CO_2 are significant innovations

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Technical Impact

- Capital and operating costs combined with low power consumption result in a total cost of electricity increase for CO_2 capture just over 1/3 that of the amine process
- Low cost alternative to amine scrubbing can enable more widespread and earlier implementation
- Scalability of technology can lead to applications for virtually any stationary fossil fuel combustion application

Technical Challenges

- Condensation in supersonic flow behaves like heat addition to the gas resulting in pressure losses
- CO_2 capture may be impeded/reduced by agglomeration or sublimation in the capture duct and cyclone particle separator
- CO_2 capture duct leading edges may be adversely affected by particle impact
- Residual corrosive species in flue gas may impact material selection, though a benefit is that these species condense before CO_2
- Design of the efficient CO_2 self-pressurization system

Development Path

- Develop initial nozzle and diffuser contours using Quasi 1D analysis codes
- Preliminary CFD analysis of the simplified ICES problem
- Visualization test with laser diagnostics
  - design and manufacture small scale ICES nozzle based on initial CFD results with optical access to regions of interest
  - determine condensation zone and possibly average size of CO_2 ice particles
  - capture images showing migration of CO_2 particles to outer wall
- CFD anchoring for swirl, condensation, and particle migration problems
- Build and test subscale ICES CO_2 separation unit
- Evaluation, development and demonstration of the subscale ICES system (Phase II)

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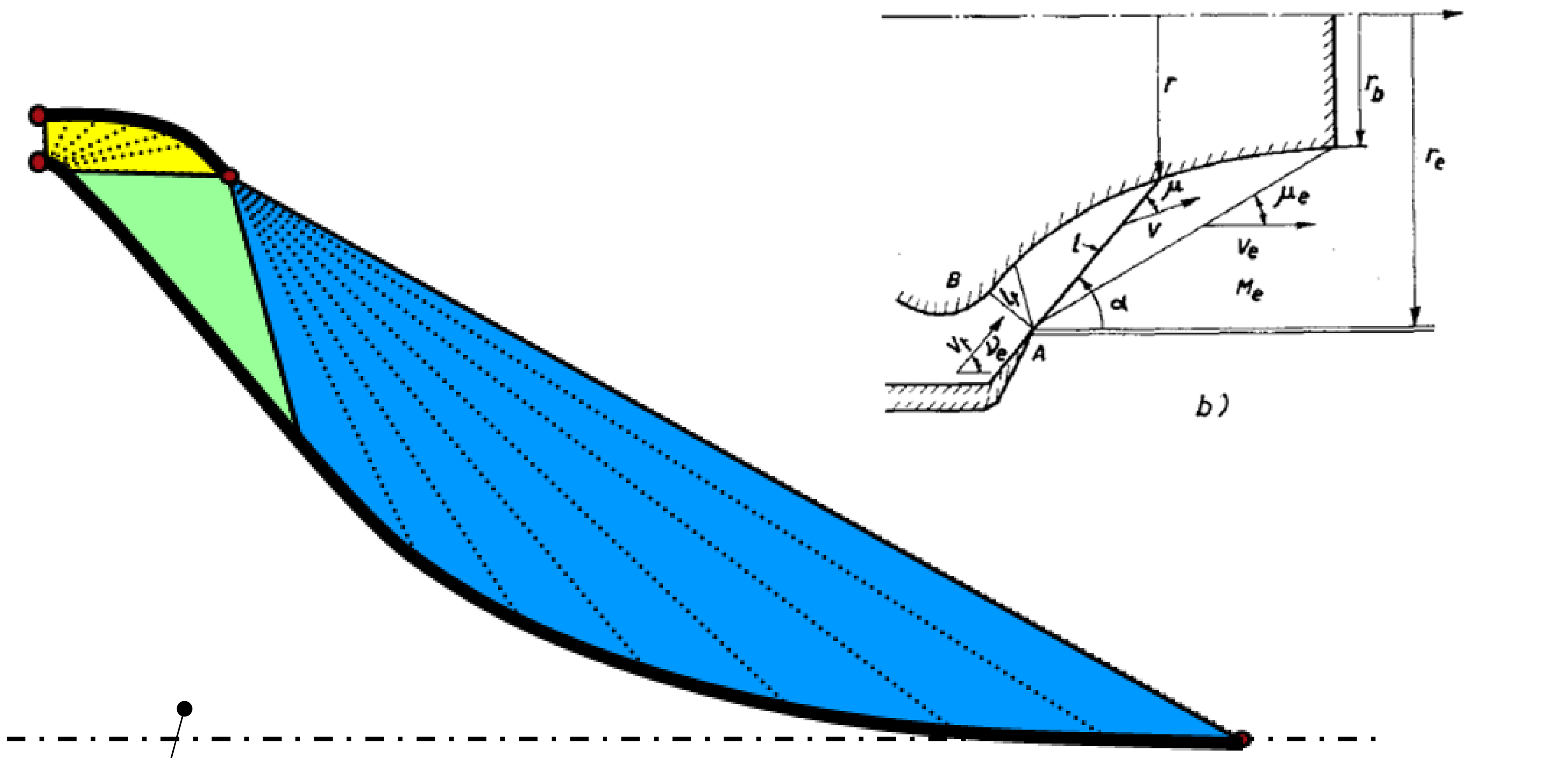
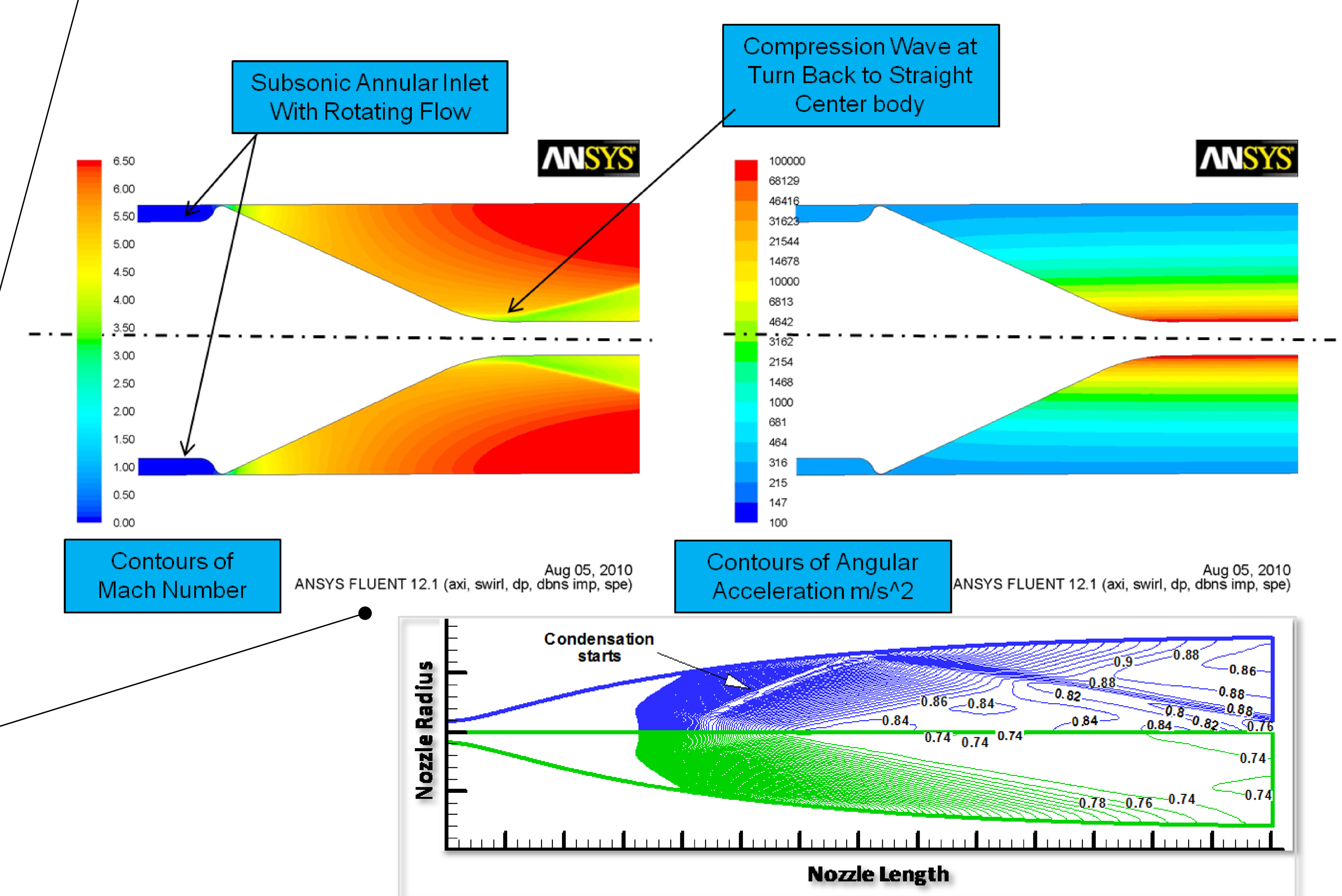
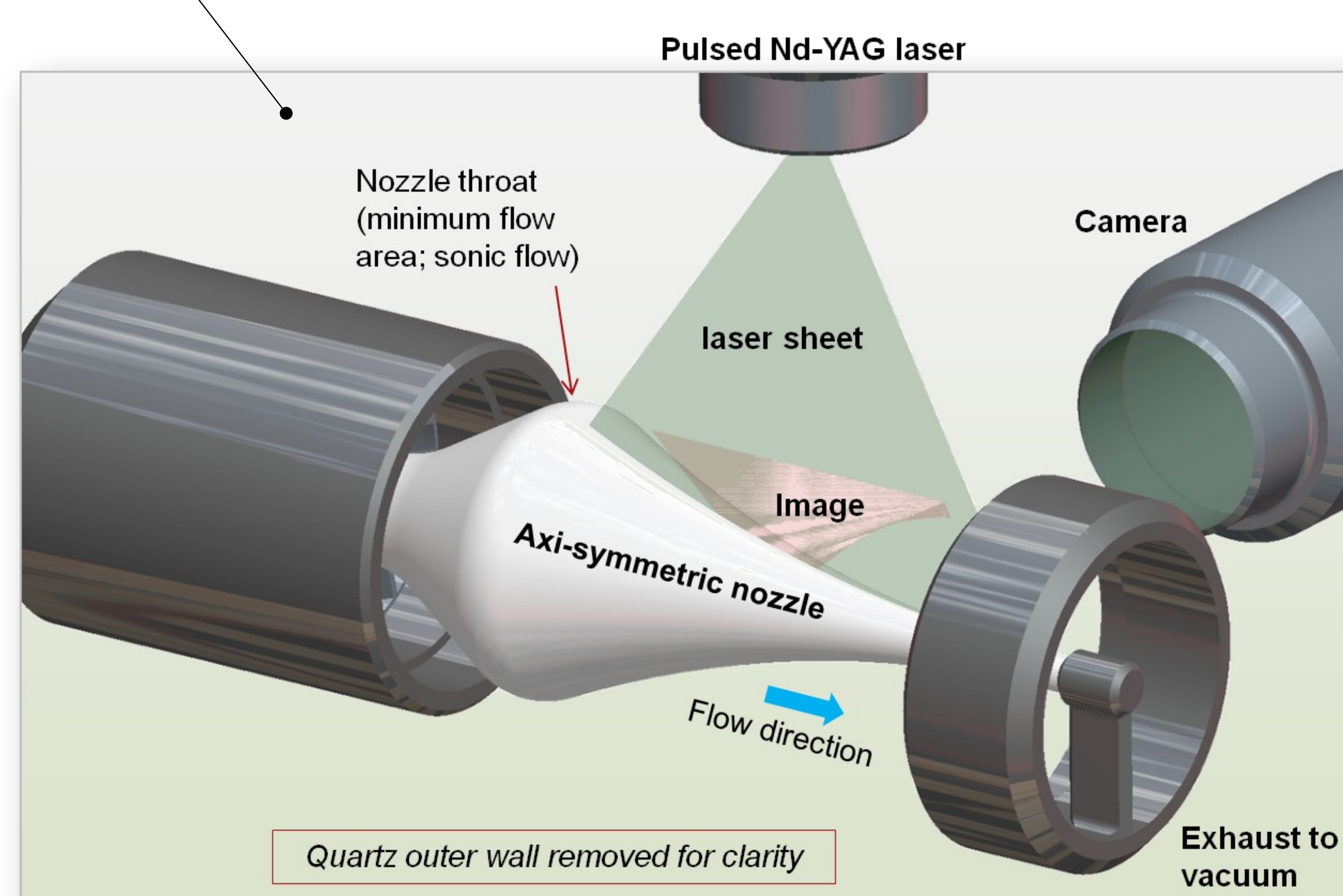


Initial contour development effort



Annular swirl duct with supersonic expansion and CFD of water condensation in existing nozzle



Schematic of the visualization test

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