FUEL INJECTION AND COMBUSTION PROCESSES IN SMALL JET ENGINES

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The following research activities in small jet engines was carried out at the Turbo and Jet Engine Laboratory :

1. Atomization systems for small combustors

2. Design of novel small combustors

3. Combustion and ignition processes study

1. Atomization systems for small combustors

The objective:

Feasibility study of swirl and air-blast atomizers
to function as fuel supply system of small jet engines

1. NOVEL FUEL SYSTEM STUDY

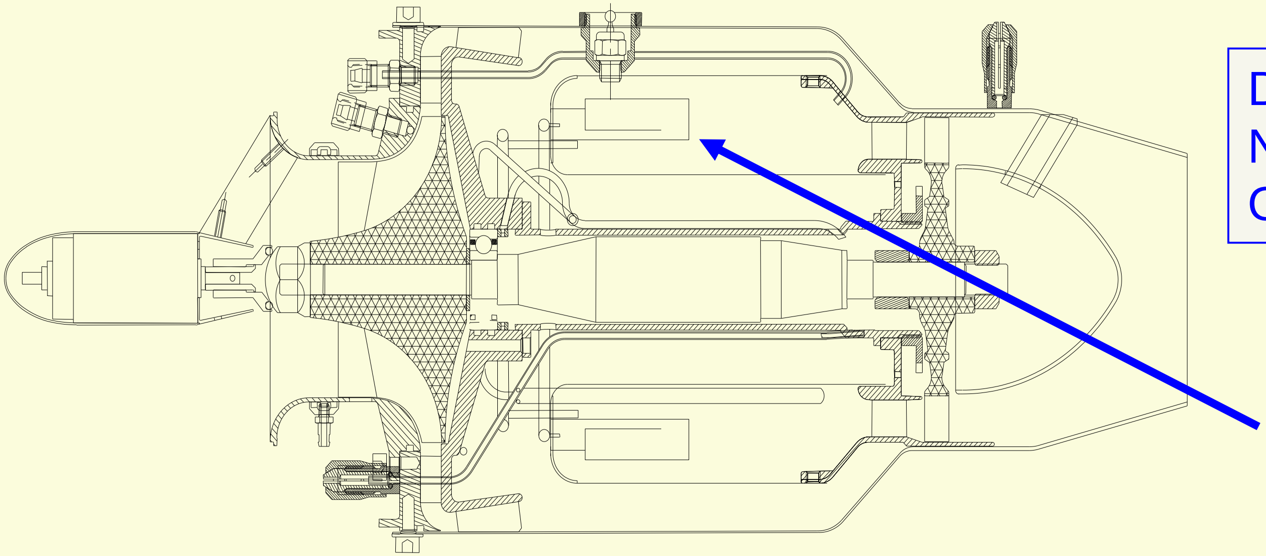
Fuel systems of small jet engines in many cases incorporate **vaporizers**.

Advantageous:

- Low fuel pressure
- Simplicity

Drawbacks:

- Ignition problems
- Poor heat balance between liner and the vaporizer case.



Drawing of the AMT Netherlands B.V. Olympus Design.

VAPORIZER

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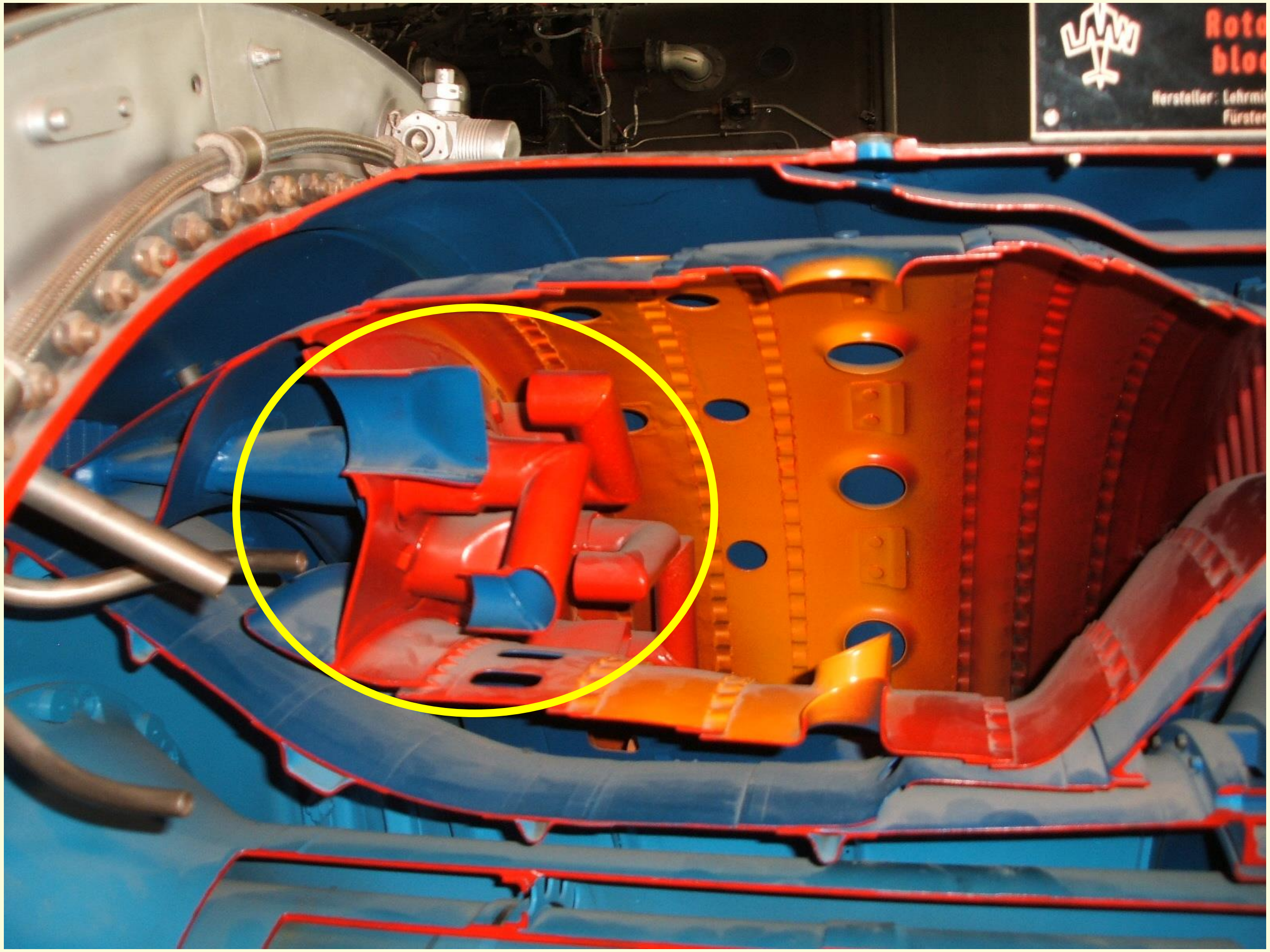


TYPICAL VAPORIZERS

Turbo and Jet
Engine Laboratory
Technion – Israel
www. jet-engine-lab.technion.ac.il

Swirl atomizers.

•Well studied.

•Difficulties to scale (very small components for small engine).

•Require high fuel pump pressure.

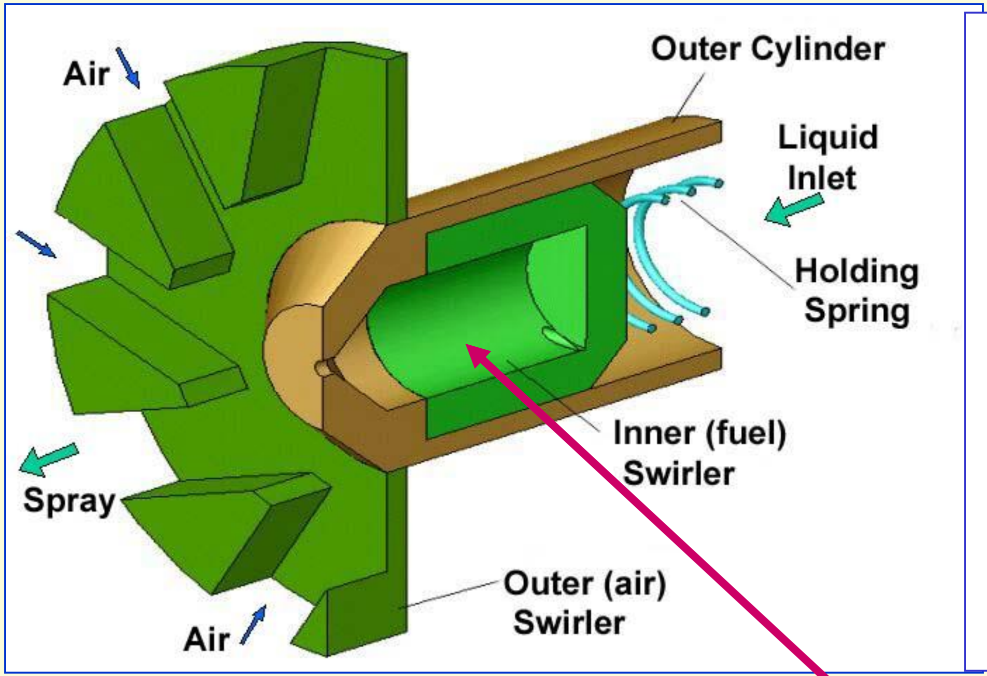
Air-blast atomizers

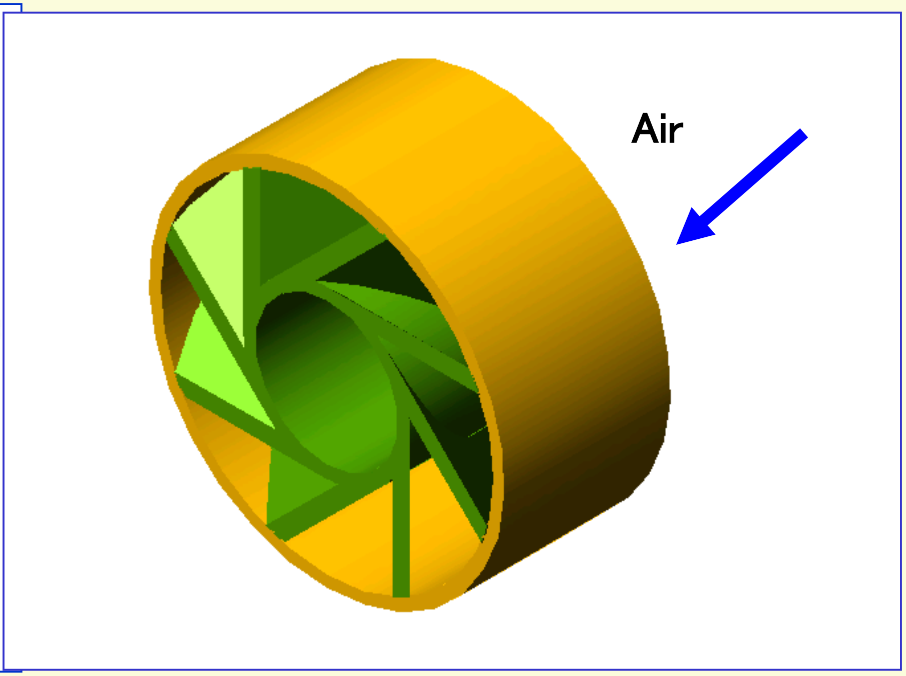
•Well studied, require relatively low fuel pump pressure.

•Mechanically complicated and therefore are difficult to adapt for small engines.

•Miniature air-blast atomizers are not adequately studied.

•The current work presents comparison of modified air-blast simplex atomizer where air is delivered to fuel spray through axial or radial channels with vanes' angle of 45^0.

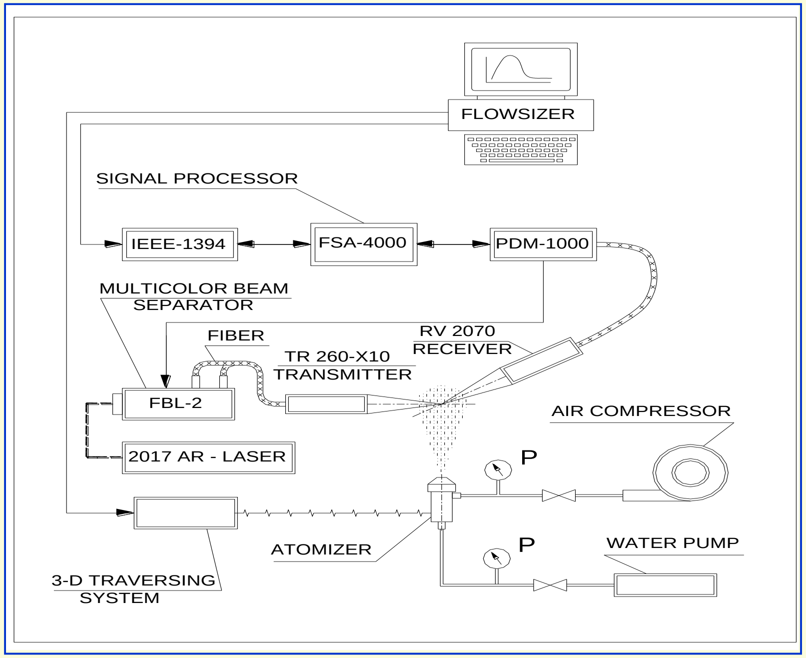




swirl atomizer

The same swirl atomizer was used for both air swirlers

Three-dimensional schematic drawing of studied atomizer



Experimental set-up

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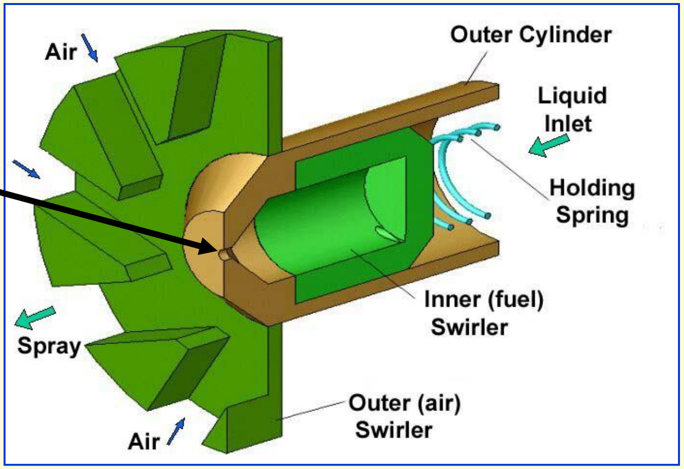
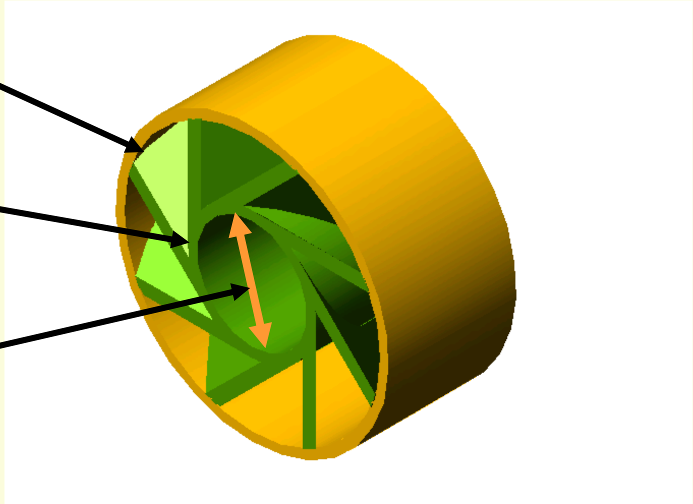
Principal atomizer dimensions:



- •discharge orifice diameter – 0.4 mm;
- •swirl chamber diameter – 3 mm;
- •two inlet ports – 0.4 mm diameter;
- •outer diameter of the air swirler – 14/13 mm;
- •inner diameter of the air swirler – 8/7 mm;
- •vanes height – 1.6 /3mm;

(/data for axial swirler)

- •outer diameter of the cylinder – 6 mm.

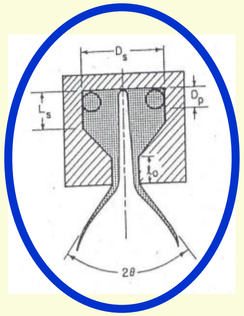


Atomizer's parameters and tests range

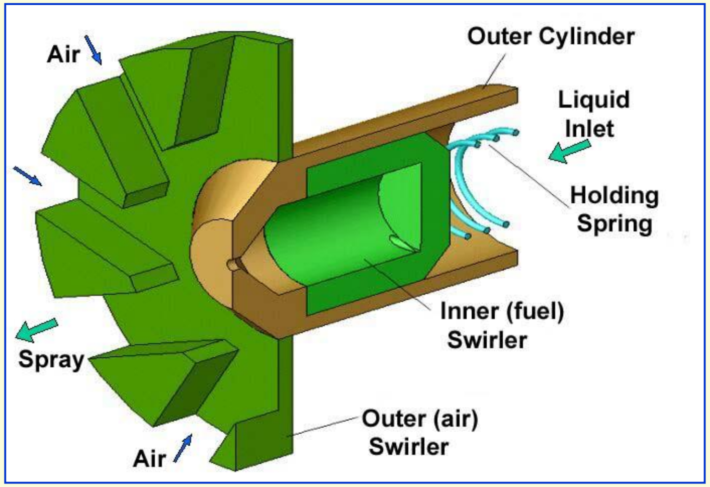
•Atomizer Flow Number FNSI was $7.4 \cdot 10^{-8}$ [m^2],

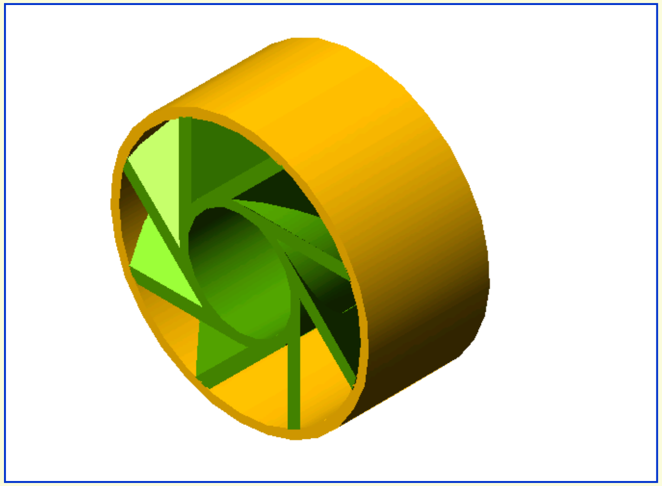
$$FN = \frac{\dot{m}_l}{(\Delta P_L \rho_l)^{0.5}}$$

•discharge coefficient was 0.415



•air pressure drop was varied from 0 - 0.1 bar





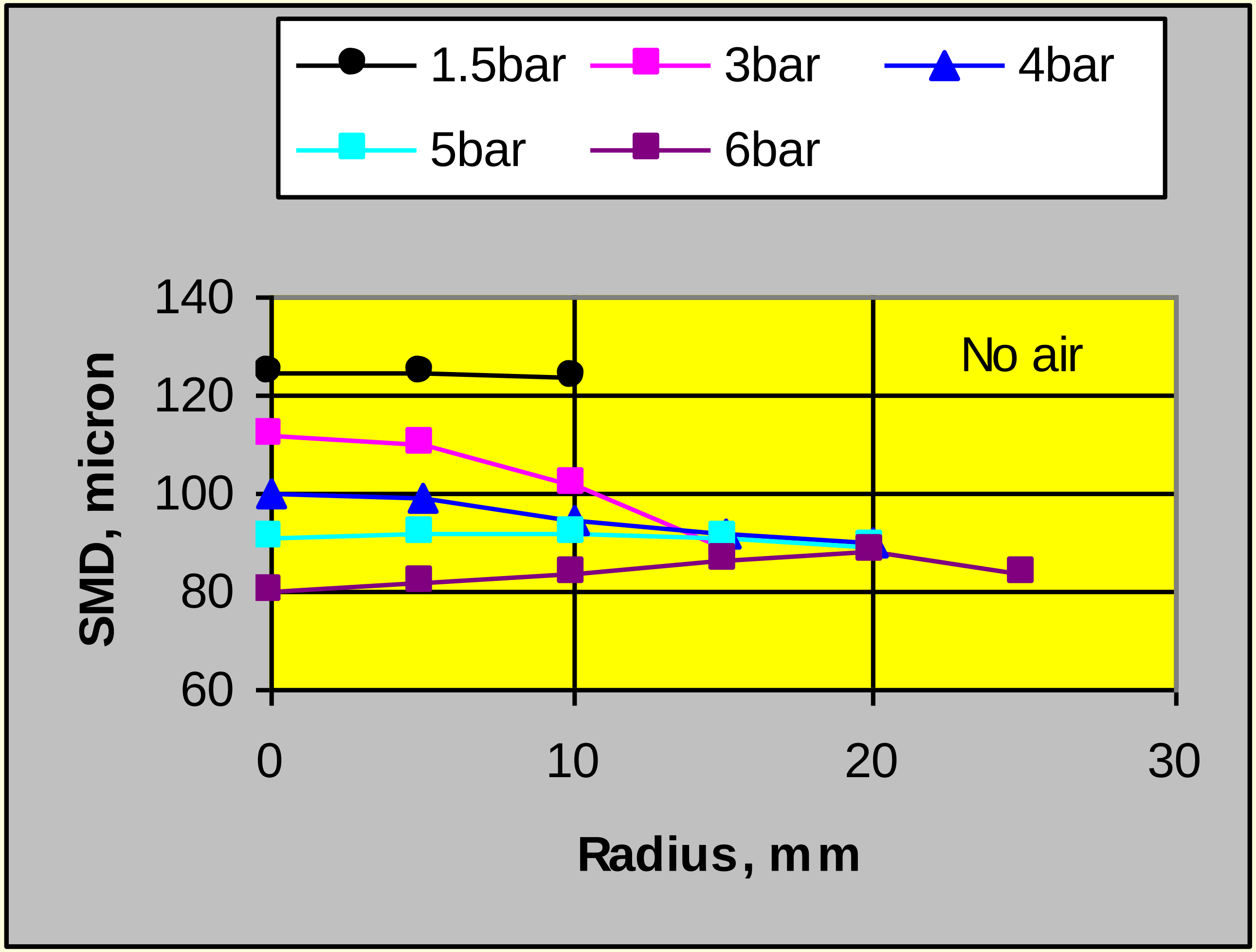
Tests range

•The liquid (water) pressure drop was varied from 1.2 to 5 bars, in line with the corresponding parameters of small jet engines.

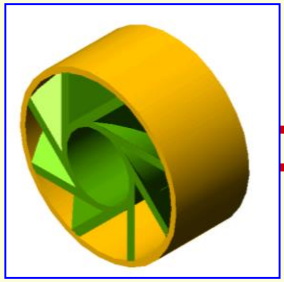
•The air-to-liquid mass ratio (ALR) was varied in the range of 1 to 4.

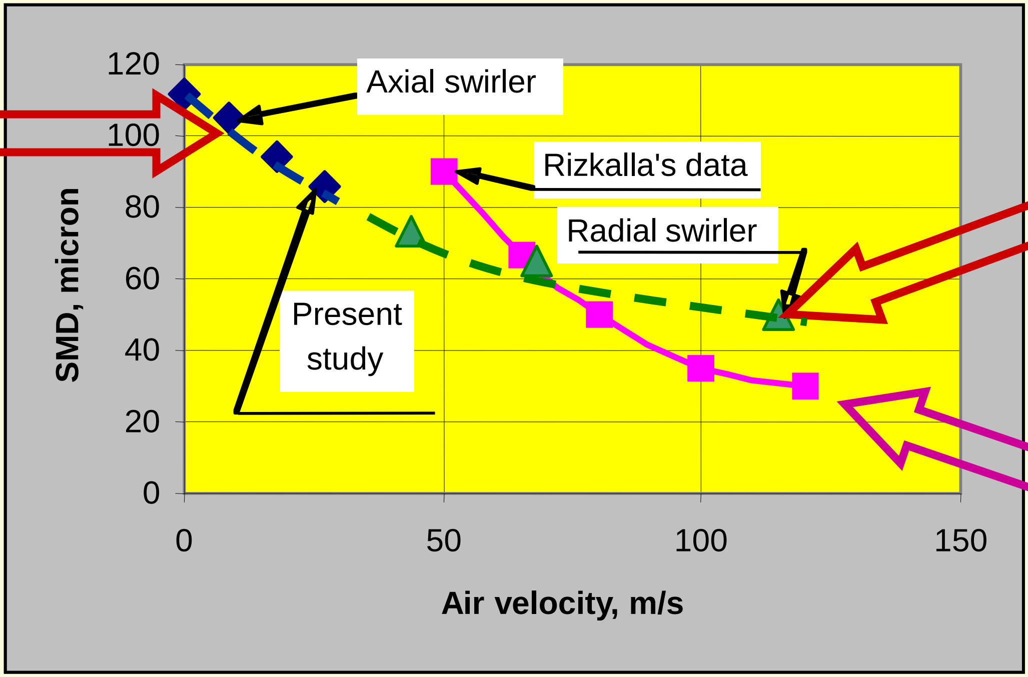
T E S T   R E S U L T S

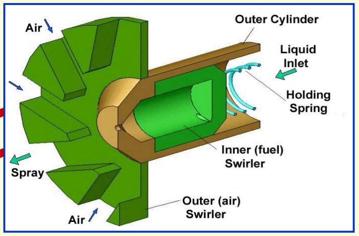
1. Droplet size. Effect of the liquid pressure drop. No air



3 **Droplet size:** comparison with other studies







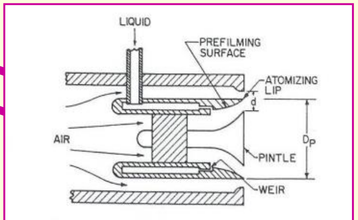
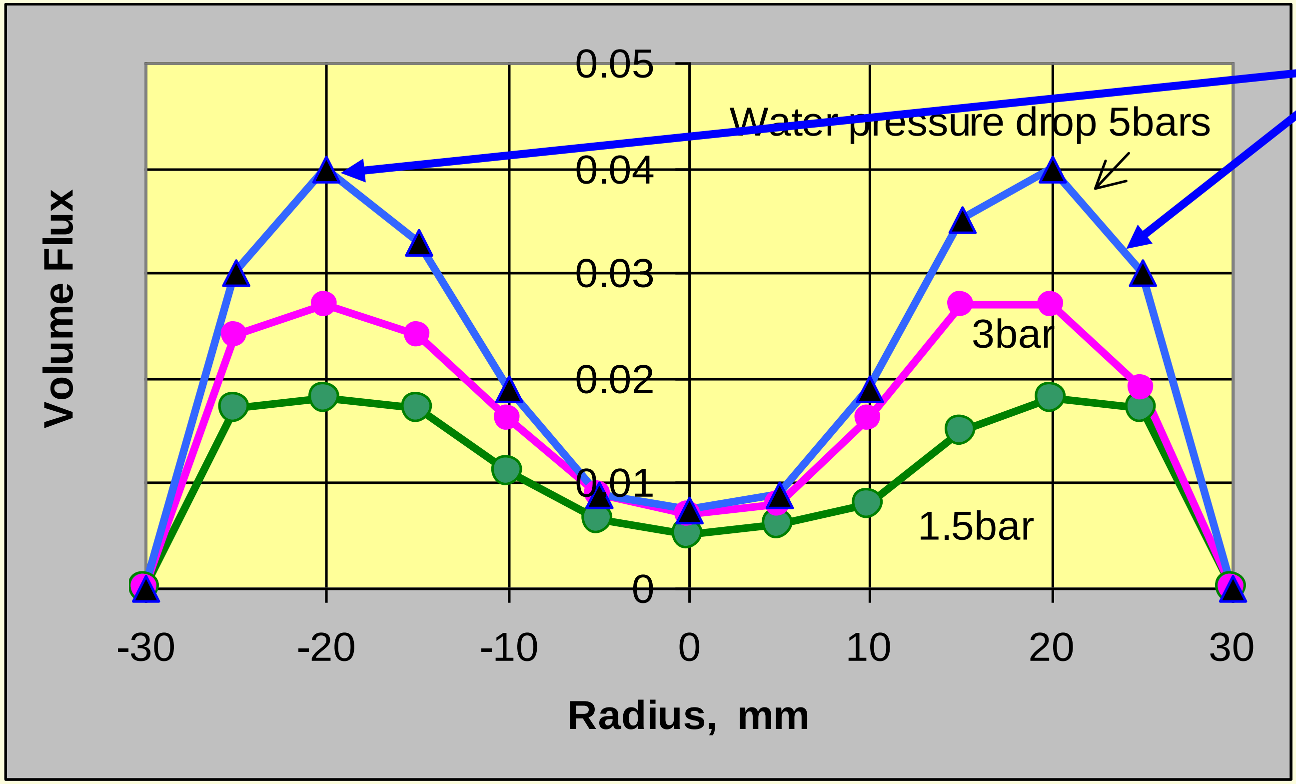


Figure 6.34 Prefilming type of airblast atomizer [77,

Rizkalla et. al.

The effect of air velocity in our study was weaker. However "our" droplets have smaller diameter for low air velocities

2. Flux distribution



HOLLOW CONE PATTERN

THE MORE WATER PRESSURE DROP THE GREATER NONUNIFORMITY FLUX

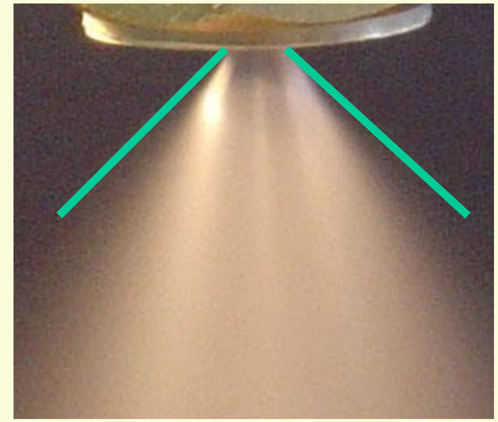
Liquid flux distribution (cc/(cm2/s)) along radius, air pressure drop 0.01 bar

TEST RESULTS

Cone Angle; Swirl Atomizer, No air

3 bars

5 bars



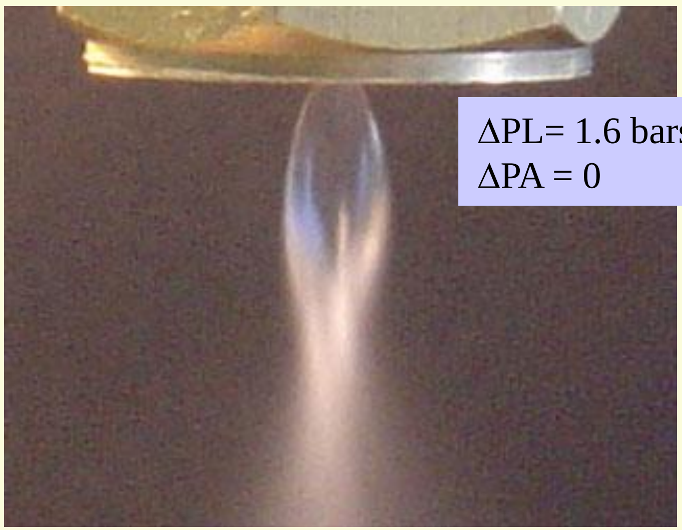
6 bars

Cone angle θ increases with liquid pressure drop, $\theta_{maximum} = 90^0$

TEST RESULTS

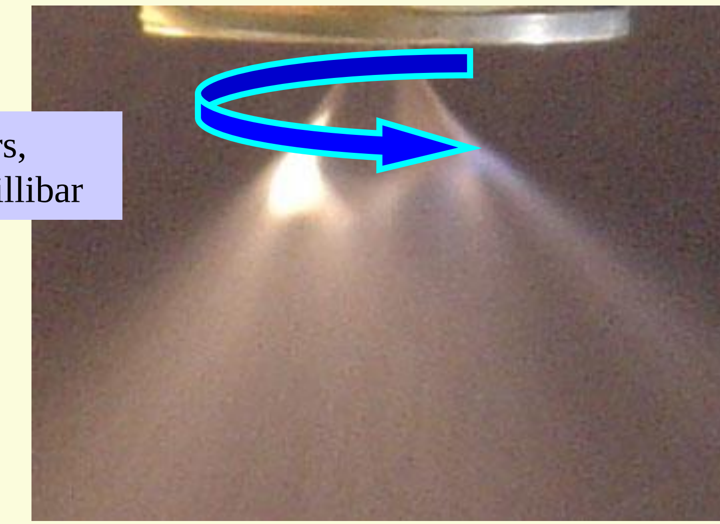
Cone Angle. Air-blast Atomizer

Two atomization modes were observed for small change of the air pressure drop. Reason: Air pressure gradient at the air jet exit.



ΔPL= 1.6 bars,
ΔPA = 0

ΔPL = 1.6 bars,
ΔPA = 0.51millibar



Cone angle increases jump-wise

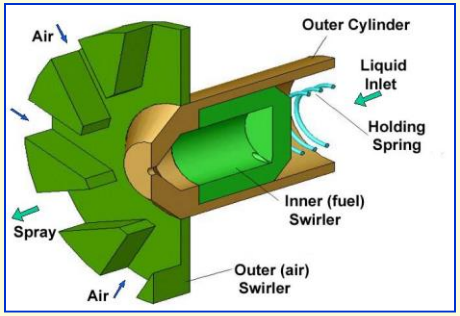
Development of this phenomenon can be seen in movie

EXAMPLE OF THE JUMP CHANGE OF THE OPERATING MODE OF THE ATOMIZER:

SUMMARY

- Miniature airblast atomizer, with radial and axial air vanes and simplex pressure atomizers were studied.
- The strong effect of the air on the SMD was demonstrated.
- Dimensions and performance seems suitable for small engine application
- Tests are still needed to reveal optimal performance

Principal results: Swirl atomizer

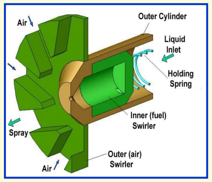


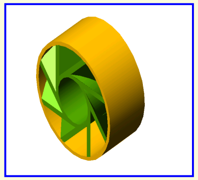
- When liquid pressure drop increases from 1.5 to 5 bars the droplet size decreases from 110 μm to 60 μm, the size of droplets grows from the spray center to its periphery whereas their velocity decreases.

- Maximum liquid flux also shifts from the center of the spray to its periphery.

- The spray angle increase from 75 to 90 degrees with liquid pressure drop rise.

Principal results: Airblast atomizer





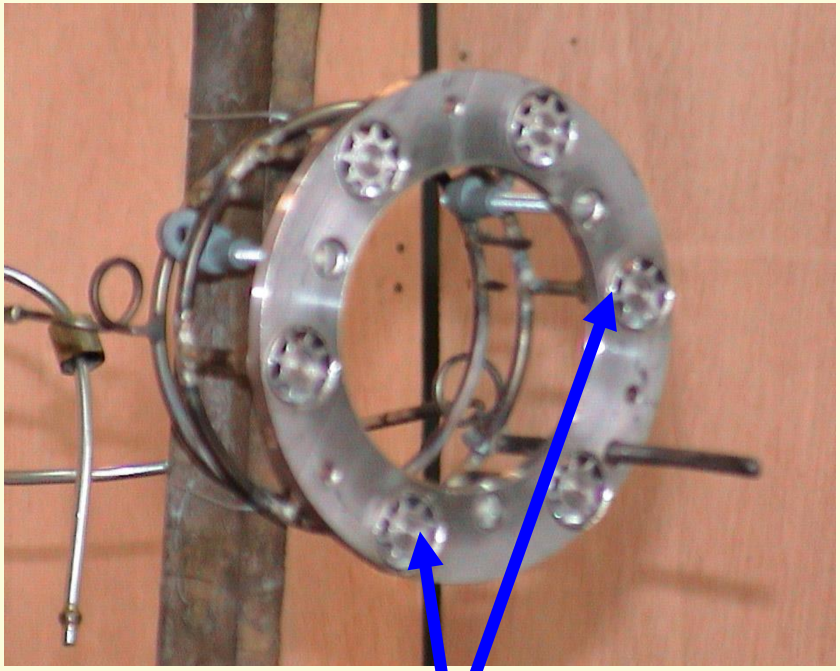
- The droplet diameter decreases drastically when air pressure drop grows from 0 to 0.02 bars but only slowly with further rise in the pressure drop.
- Liquid pressure drop has little effect on the droplet size if air pressure drop exceeds 0.02 bar.
- The air-to-liquid mass ratio has little effect on droplet size in the range of 1 to 4.

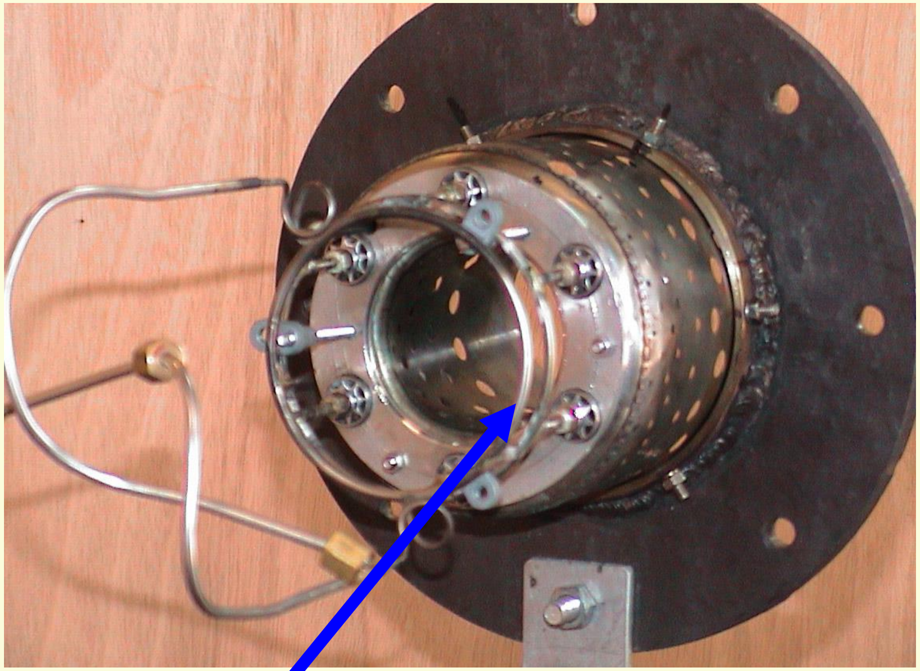
• The jump-wise spray cone angle (till 130^0) occurs at low liquid pressure drop (“onion” stage) while increasing air pressure drop.

• Reason: sub-ambient air pressure within jet that helps to overcome the liquid bubble surface tension.

•The large spray angle make it useful for small jet engines due to short residence time of droplets.

The tested air-blast atomizers with axial swirlers were installed to experimental model of the combustor





Axial swirlers

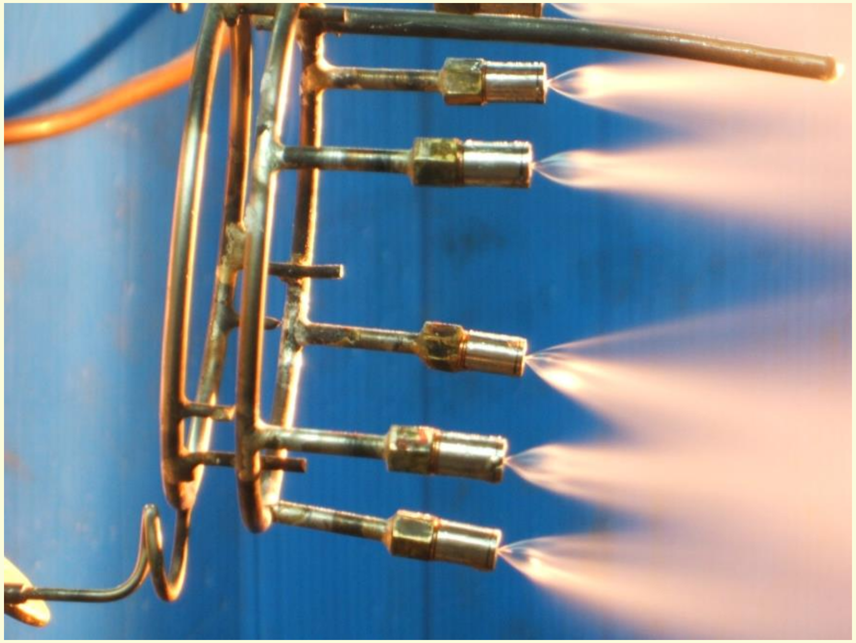
Assembly of small combustor

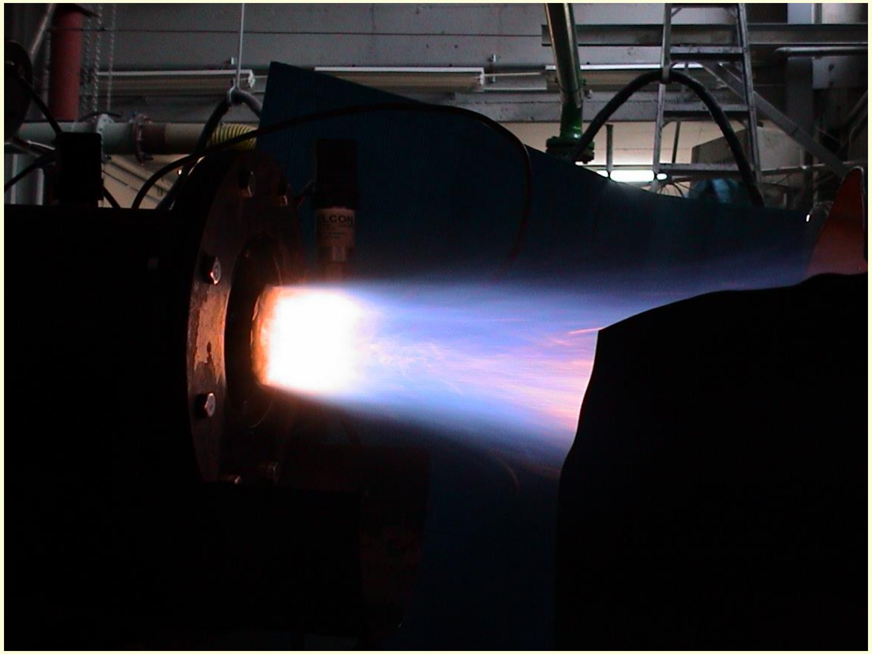
The combustor model is similar to the Netherlands B.V. Olympus design

TEST OF MANIFOLD

COMBUSTOR TEST

SWIRL ATOMIZERS

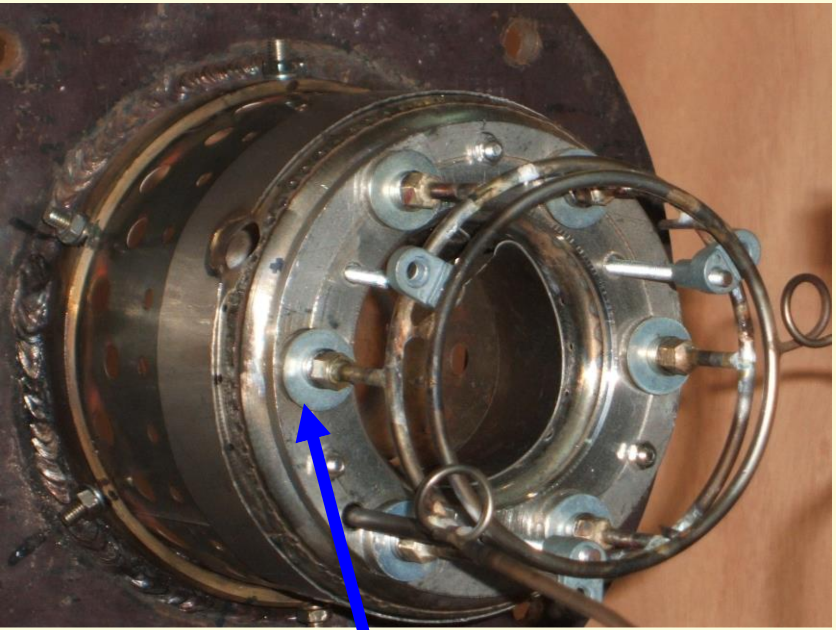


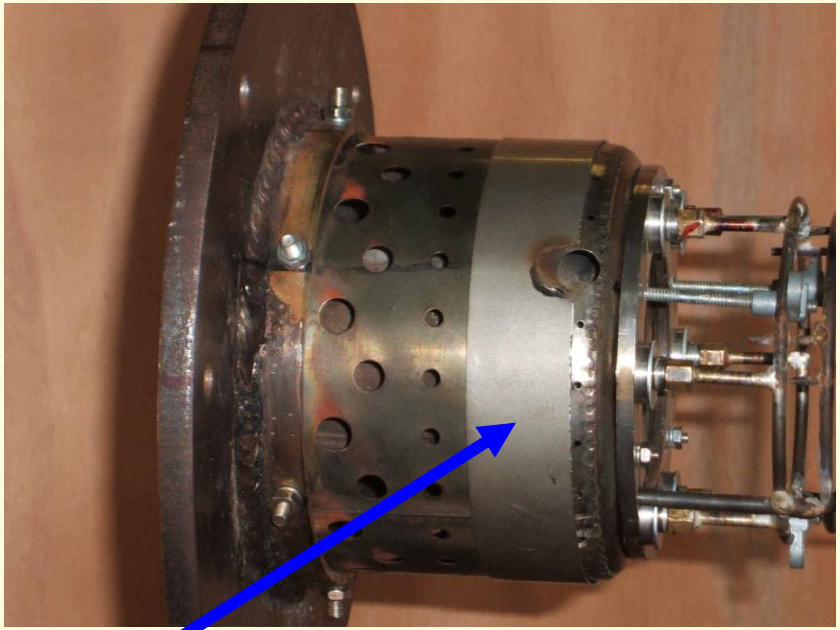


TESTS SHOW THAT COMBUSTION OCCURES OUT OF THE COMBUSTOR. REASON: TOO HIGH AIR VELOCITIES AT THE PRIMARY ZONE

First combustor model

MODIFIED COMBUSTOR





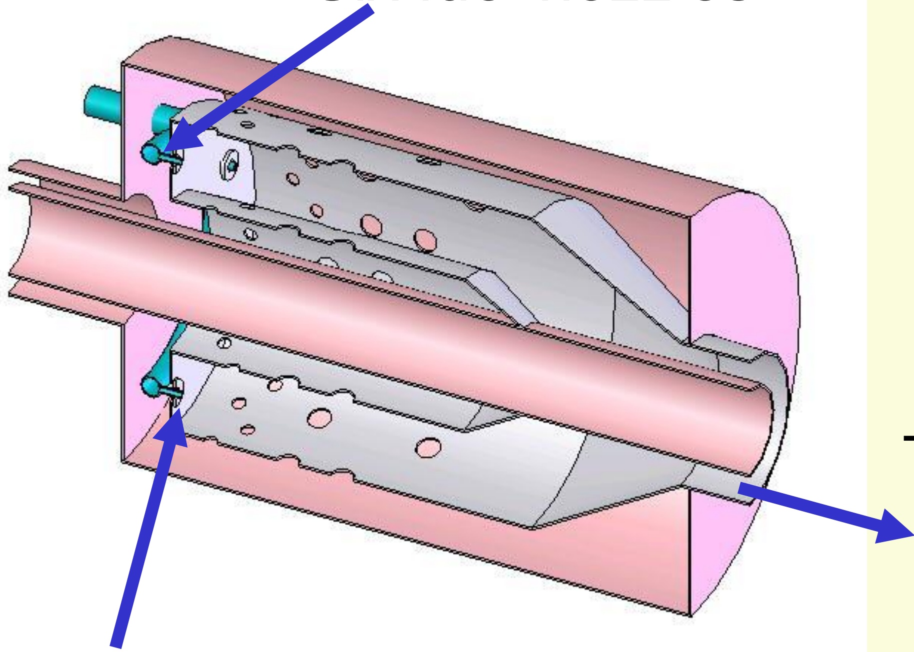
•AXIAL SWIRLERS AND 2 ROWS OF HOLES IN THE PRIMARY ZONE WERE CLOSED.

•SUCCESFUL IGNITION AND SHORT COMBUSTION LENGTH WERE ACHIEVED.

SMALL COMBUSTOR DEVELOPMENT FOR MICRO GAS TURBINE

METHANE IS USED AS A FUEL

Six fuel nozzles



OUTER LINER DIAMETER

= 70 mm

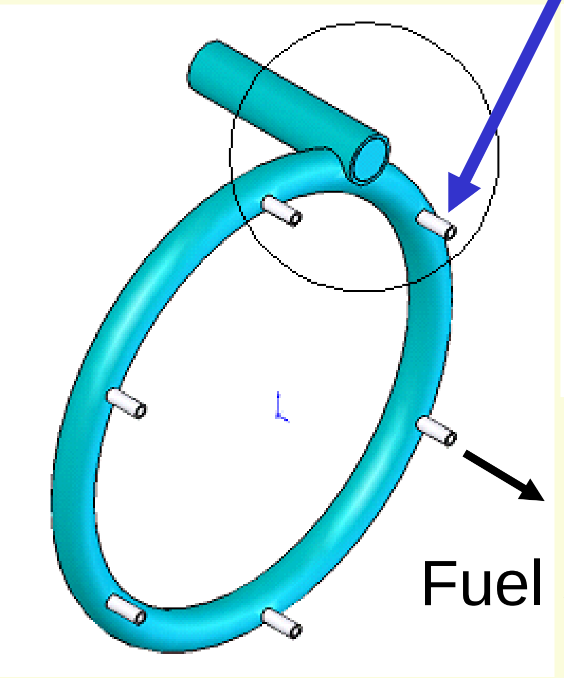
INNER DIAMETER = 35 mm

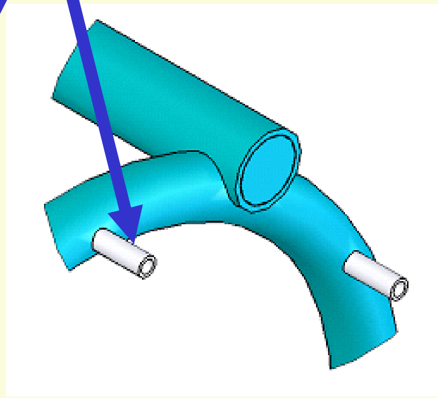
To turbine

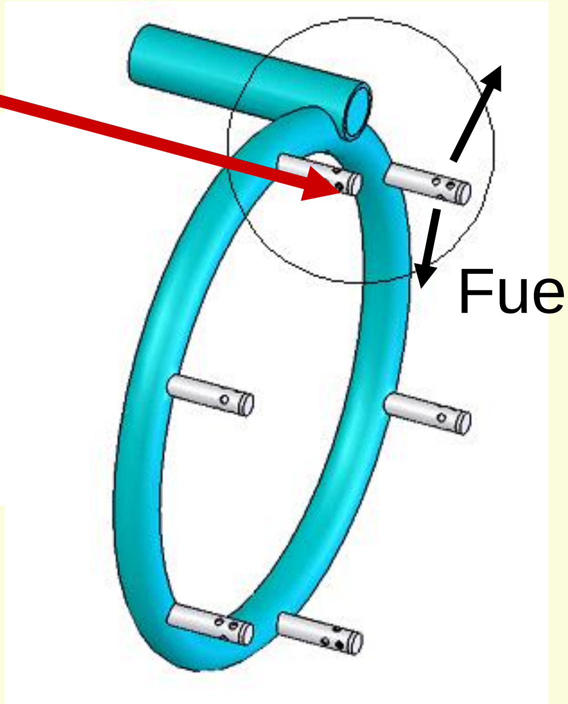
Six spacers for air supply of primary zone
And creation recirculation zone

Modified combustor

1. Modified manifold







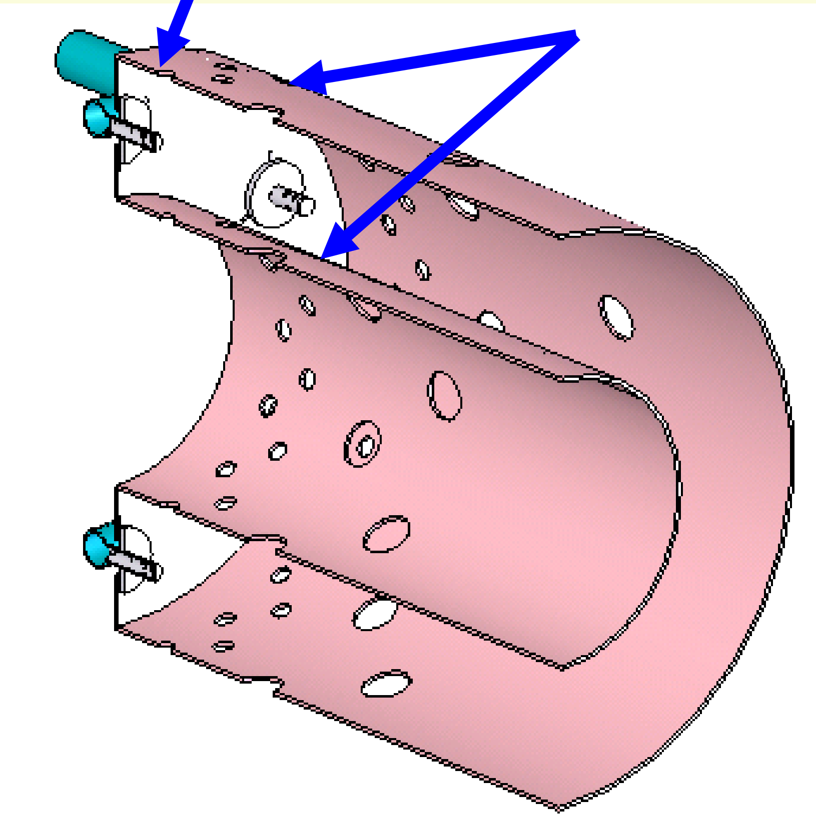
Fuel supply

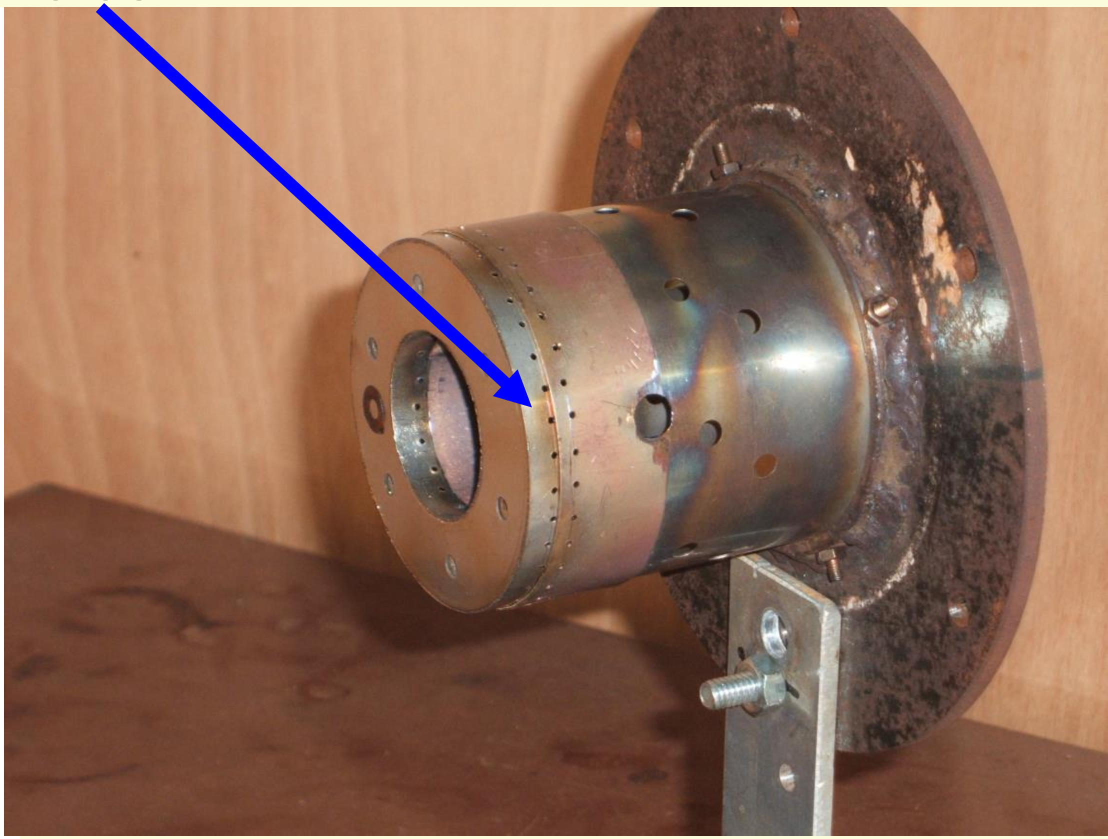
Fuel supply

MODIFIED COMBUSTOR

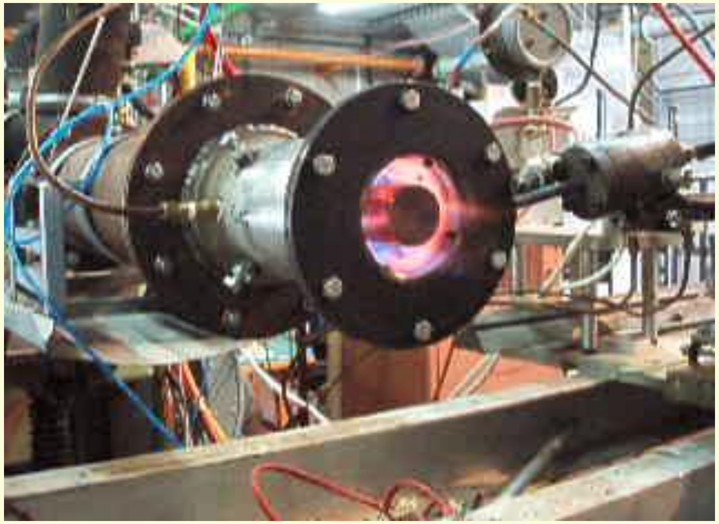
Modified fuel nozzles

Additional holes

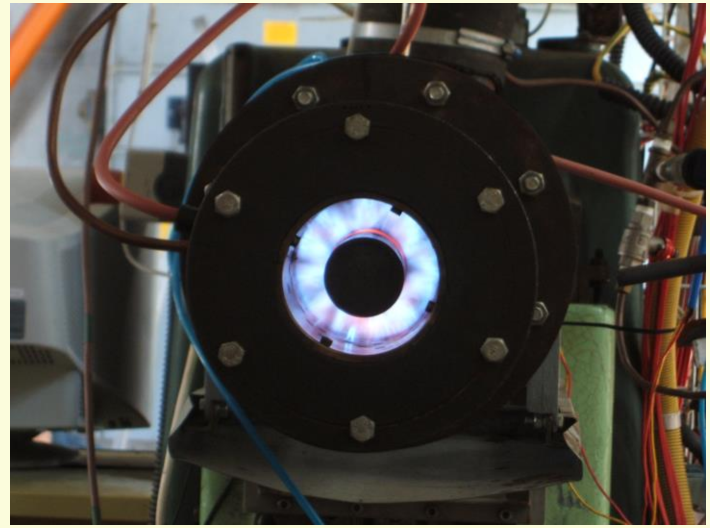




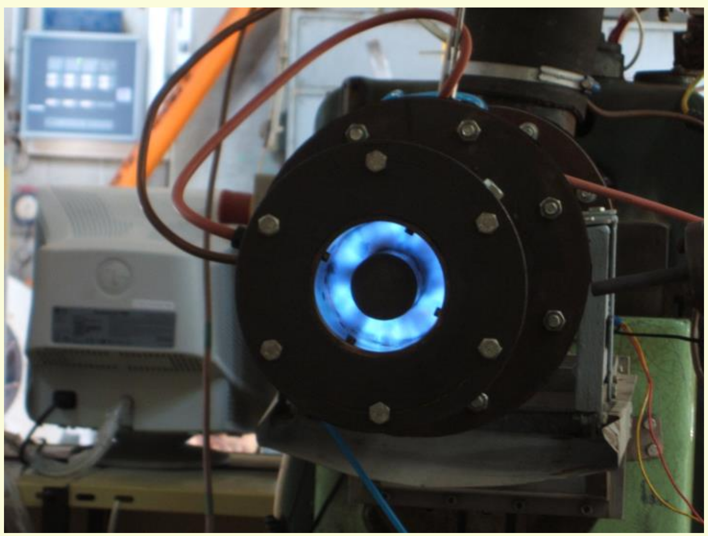
Tests demonstrated stable combustion



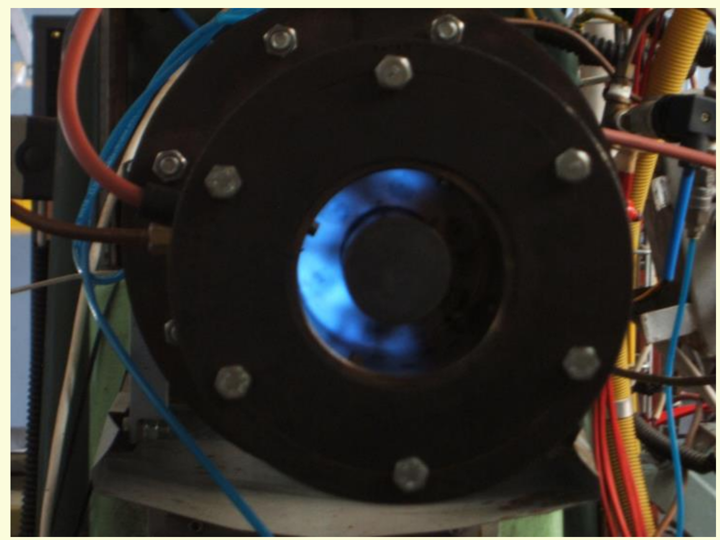
a)



b)



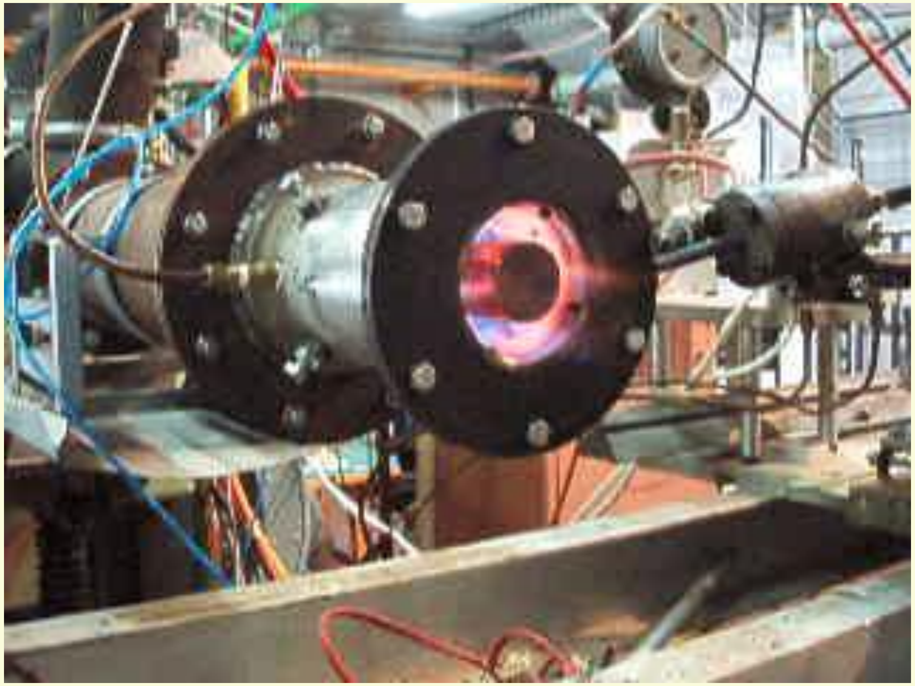
c)



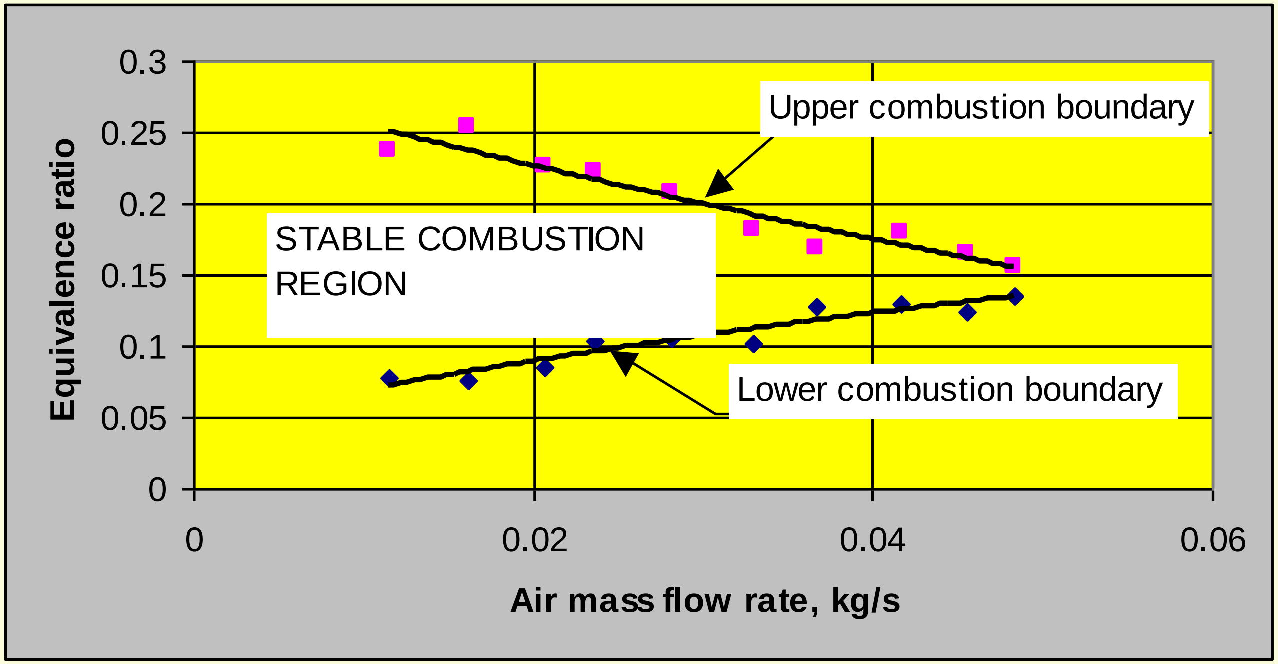
d)

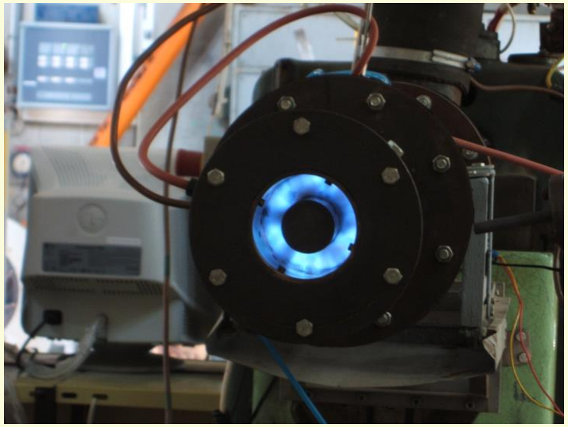
Combustion regimes: a), b) – moderate eq. ratio
c), d) – lean combustion limit (low equivalence ratio)

Methane Combustion in small combustor for the micro Gas Turbine



STABLE COMBUSTION REGION





It can be seen that the stable combustion region is shifted to the field of low eq. ratios.

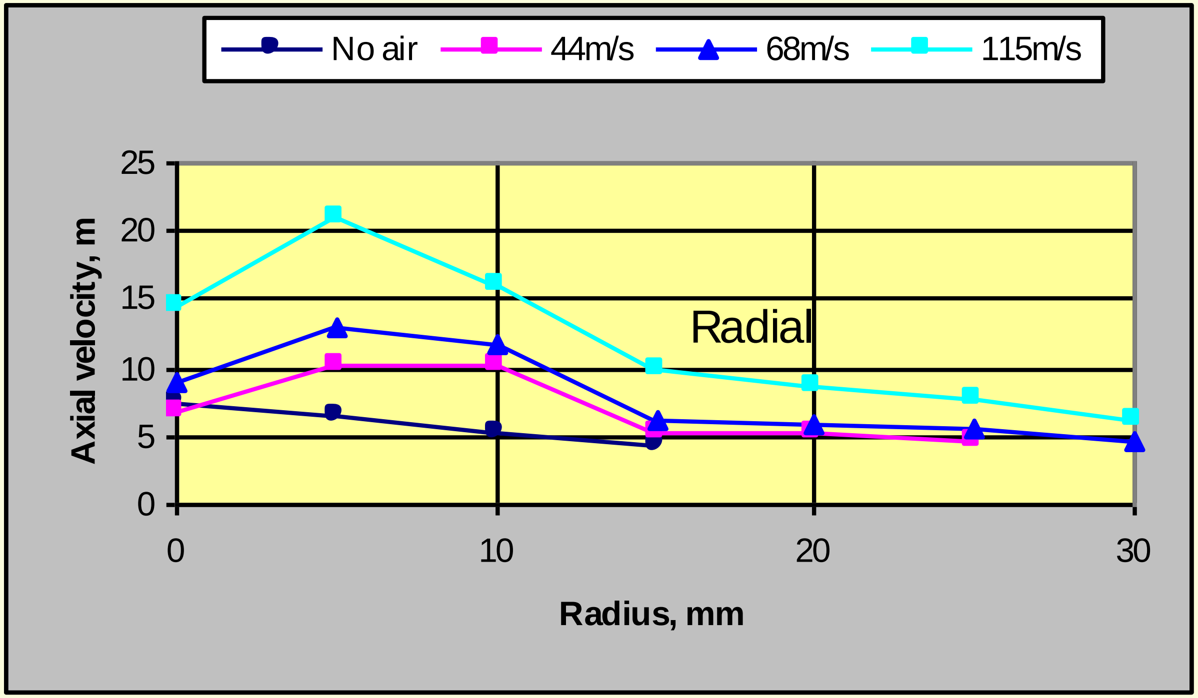
If higher operating eq. ratio need, the distribution of air should be changed

Conclusions:

- Small combustor for micro gas turbine, using Methane as fuel was developed.
- It demonstrated stable combustion over a relative wide range of air/fuel ratios.
- It is applicable for 1-5 [KW] micro Gas Turbine for electric power generation

TEST RESULTS

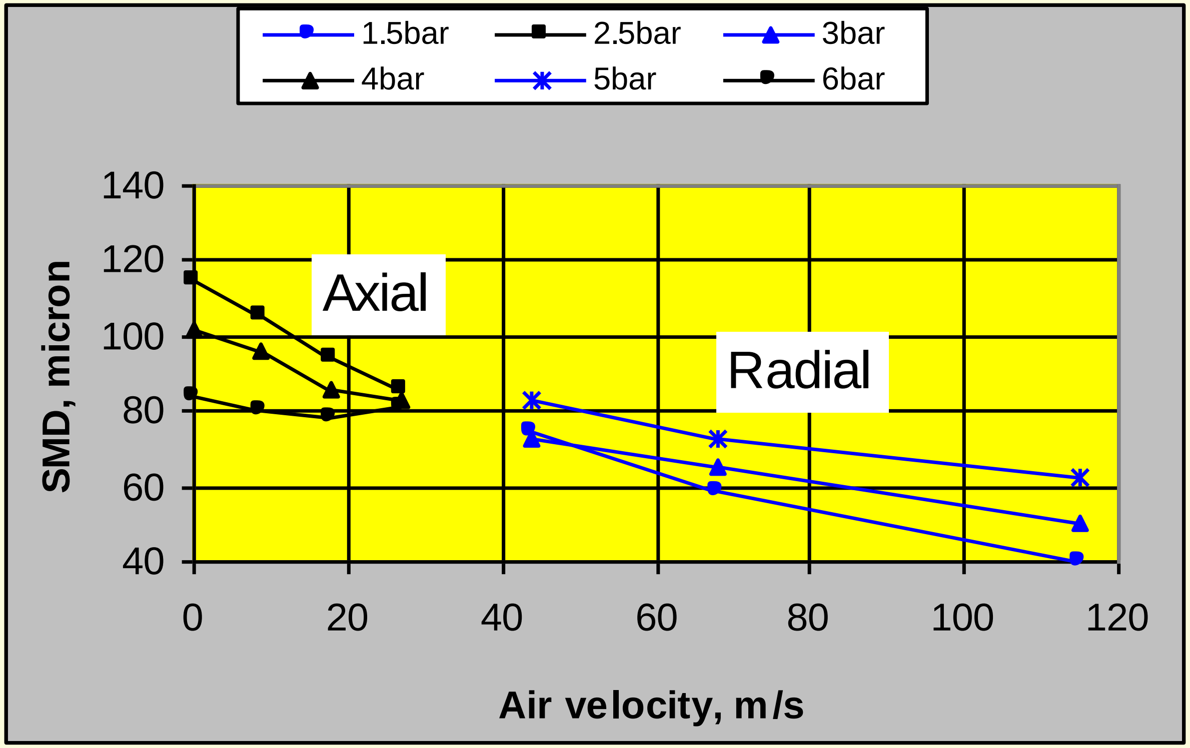
3. Axial droplet velocity

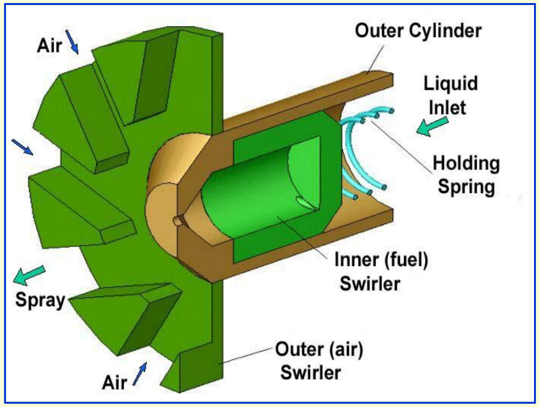


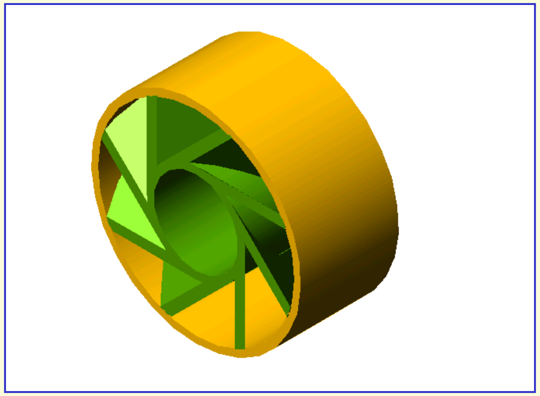
- **MAXIMUM DROPLET VELOCITY IS NEAR THE CENTRE OF THE SPRAY.**
- **FOR THE SAME LIQUID PRESSURE, THE DROPLETS VELOCITY ARE HIGHER FOR AIRBLAST ATOMIZER**

T E S T R E S U L T S

2. Droplet size. Comparison axial and radial swirlers







DROPLET SIZE DEPENDS ONLY WEAKLY ON LIQUID PRESSURE DROP FOR AIR-BLAST ATOMIZER

SMD distribution along radius for the axial and radial swirlers

SUCCESSFUL SPARK IGNITION AND COMBUSTION SHOW THAT SUCH ATOMIZERS CONFIGURATION CAN BE USED FOR SMALL JET ENGINES

FURTHER STUDY OF THE COMBUSTOR FOR WIDENING OF THE OPERATING RANGE AND OF THE AIR-BLAST ATOMIZERS APPLICATIONS SHOULD BE CARRIED OUT

First combustor model does not work in the required way:
The flame was out of the liner.

The reason was too high air and gas velocities within the primary zone

Modification was required

IT WAS MODIFIED BY THE FOLLOWING WAY:

1. FUEL SUPPLY WAS CARRIED OUT THROUTH THE RADIAL HOLES INSTEAD OF AXIAL. THE GOAL: DISSIPATE FUEL WITHIN THE PRIMARY ZONE

2. CROSS SECTION AREA OF THE RADIAL HOLES WAS INCREASED. SO FUEL VELOCITY WAS REDUCED

3. TO CREATE MORE ACTIVE PRIMARY ZONE TWO ROWS OF HOLES WERE CLOSED