# Novel Pulse Detonation Engine Concept

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# Summary

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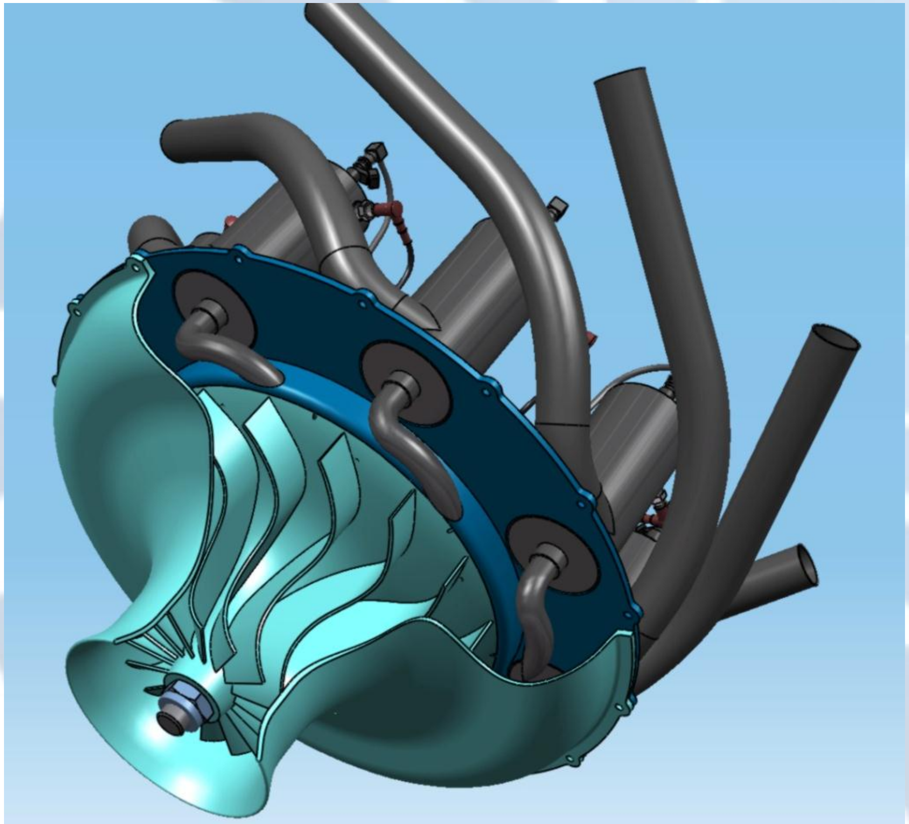
# Overview

- Ongoing FP 7 project → breakthrough propulsion system technology → a step change in air transportation
- Radically new approach → propulsion power → reduce weight, complexity, and cost
- Significant reduction of overall fuel consumption and total amount of pollutants emission
- Partners:
  - ✓ Romanian Research and Development Institute for Gas Turbines COMOTI – Romania
  - ✓ Lund University – Sweden
  - ✓ Von Karman Institute for Fluid Mechanics – Belgium
  - ✓ Institute for Applied Physics – Moldova

# Concept Description (1)

- Main idea: replacement of gas turbine by simpler system
- Advantages:
  - ✓ Reduction in engine weight;
  - ✓ Removal of cycle maximum temperature limitation
  - ✓ Reduction of engine complexity: more reliability, lower costs, shorter manufacturing time
  - ✓ Reduction of engine size, particularly length
- Operating principle:
  - ➢ Multiple rotating pulsed detonating combustors
  - ➢ Tangential exhaust of combustor flue gases to rotate entire combustor assembly;
  - ➢ Upstream compressor connected to same shaft providing high pressure to combustor

# Concept Description (2)

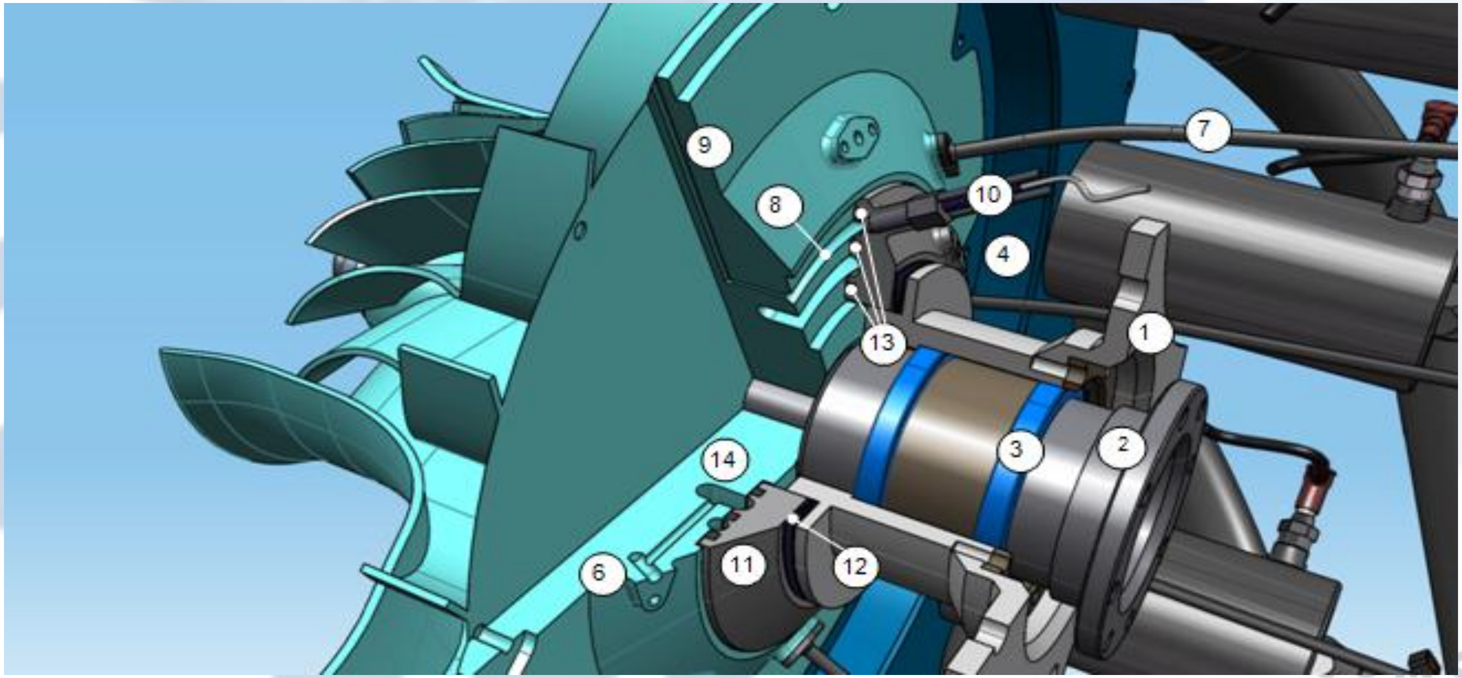


The engine diagram. Exhaust nozzle removed for clarity

- Remaining energy used to power aircraft, by:
  - Propeller (turboprop),
  - Re-axialization of flow → exhaust nozzle (turbojet)
  - **Controlled direction of combustor exhaust** →
    - **tangential velocity component drives compressor and rotating combustor assembly**
    - **axial component provides thrust by means of exhaust nozzle**

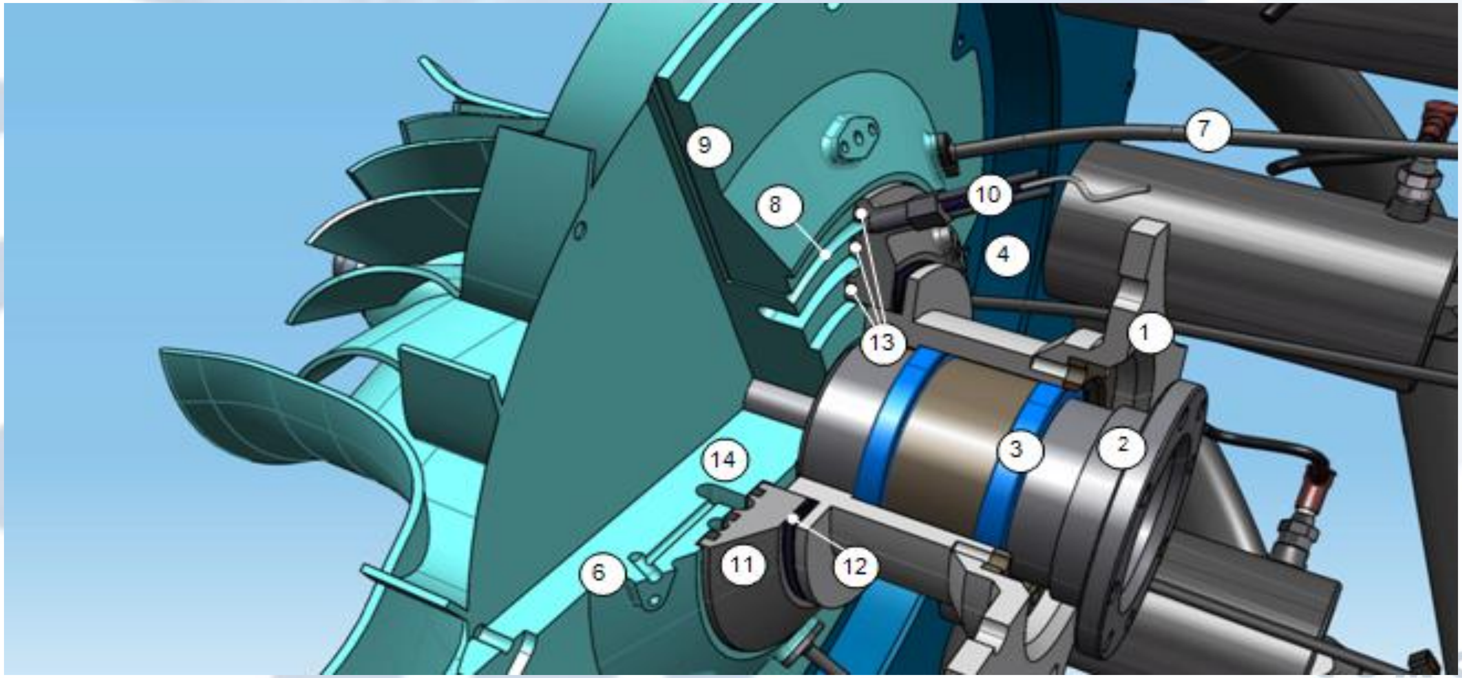
# Fuel system diagram (1)

- Fuel enters through channel 4 into stuffing box 11;
- From here, enters rotor through circular channel 14;
- Enters combustors through electronically controlled injectors through channels 6 and pipes 7
- Pressure signal transmitted through circular channel 8 to pressure transducer 10 that controls injectors



# Fuel system diagram (2)

- Sealing of circular fuel channel and pressure channel ensured by stuffing box 11, placed between bearing casing 1 and rotor;
- Stuffing box guided by slide bars preventing its rotation with respect to casing 1, while allowing axial movement;
- Sealing pressure force provided by two conical springs by means of graphite rings 13



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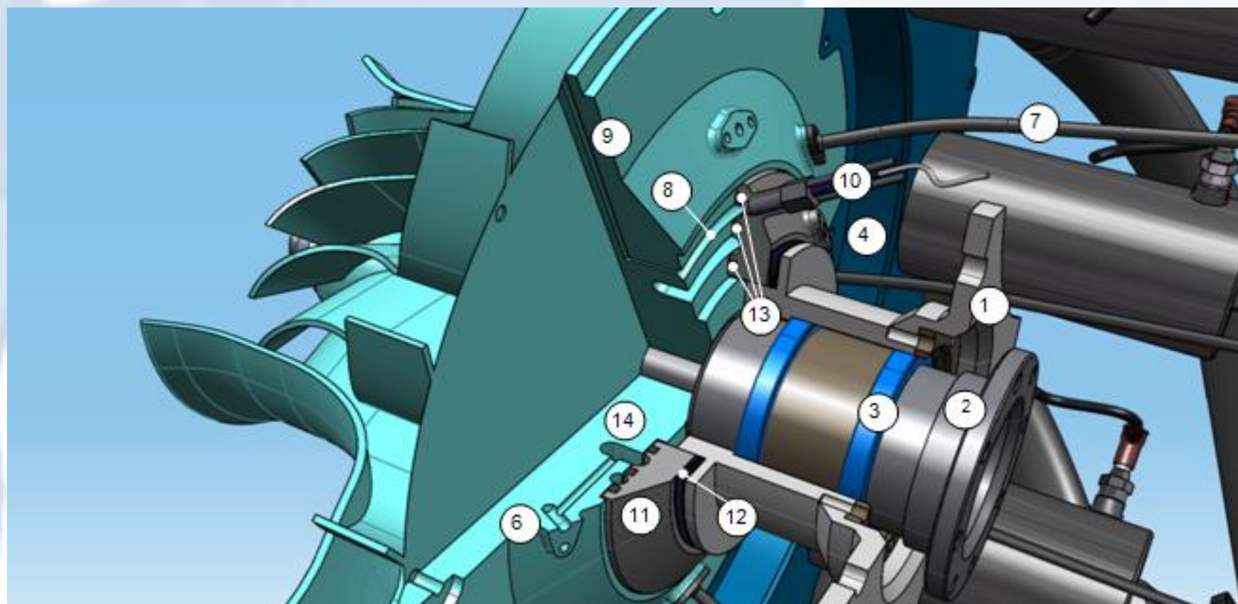
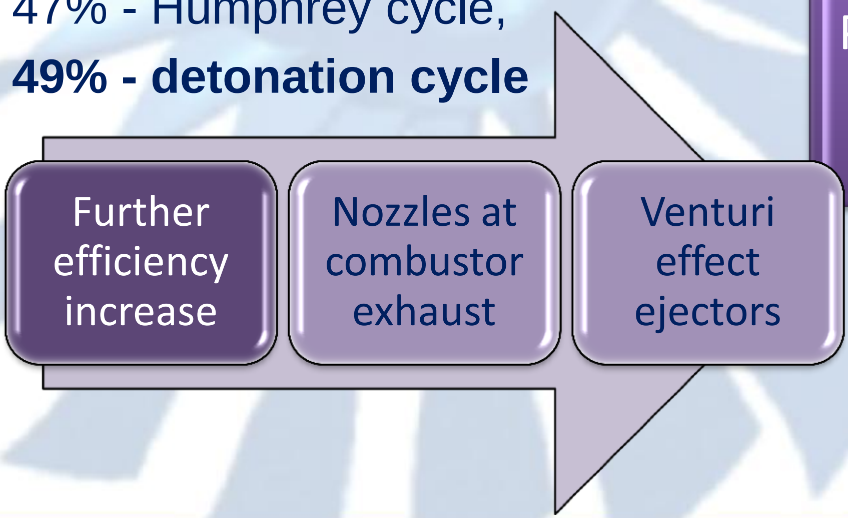
# Ignition system

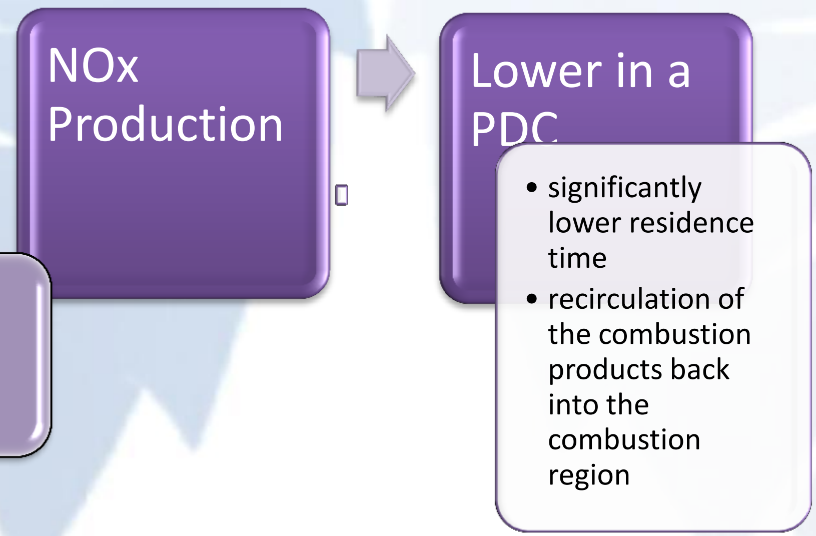
- Induction coil mounted on the rotor above exit of channels;
- Coil, as well as the fuel injectors, controlled by means of mobile brush contacts



# Pulsed Detonation Combustors (1)

- Constant volume combustor operating under oscillatory conditions;
- Significantly more efficient than constant pressure Brayton cycle
- Speed of the burning process in detonation wave → several orders of magnitude higher → thermal efficiency further increases
- Thermodynamic efficiencies:
  - ✓ 27% - Brayton cycle,
  - ✓ 47% - Humphrey cycle,
  - ✓ **49% - detonation cycle**



# High compression ratio centrifugal compressor

Further thermal efficiency increase

Safe and stable combustion in valveless PDC

Increased combustion efficiency and completeness

Higher operating frequency

Increased specific impulse

More compact combustor

Increased frequencies smooth out mechanical vibration

Increasing compressi on of the fresh gases

Increases the work obtained during the expansion process

Inertial effects

Improving compressor operating conditions

# State of the Art (1)

- Detonation process studied intensely in the last century;
- First observed in gaseous fuels by Bertolet in 1881
- Later, Chapman and Jouguet discovered that detonation products propagate at sonic speed relative to the detonation wave.
- One of the first detonation theories was the one-dimensional, detonation wave propagation theory of Chapman – Jouguet in 1905 - 1906
- Interest increased significantly with the first steps towards supersonic flight, in the mid-XX century
- Various thermodynamic cycles aiming at modeling the detonation powered engine were developed: Humphrey cycle, ZDN (Zeldovich–von Neumann–Doring) cycle Fickett-Jacobs cycle

# State of the Art (2)

- During the space race, in the ’70, new types of detonation based thrusters were studied
- Over the last decade, the number of theoretical, experimental and numerical studies increased significantly
- The practical application of detonation waves in propulsion system dates back to the 1940s but the complexity of the problem delayed the first successful demonstrator flight to as late as 2008 (DARPA's Blackswift).
- The demonstration flight was, however, at low speed, and the project was soon cancelled.
- During this time, a significant number of constructive solutions and approaches has been proposed, however none completely successful, only as far as prototypes.

# Existing Constructive Solutions

## PDE configurations

| Pure PDE, comprised of one or more detonation tubes an inlet and a nozzle | Combined-cycle PDE, typical for ramjets or scram jets | Hybrid PDE, that replaces classical deflagration combustor with a PDE |
|---|---|---|
| • Low inlet pressure at high altitude<br>• No detonation | • Only works efficiently until Mach 5 | • enhance the engine performance<br>• reduce flight time<br>• decrease pollutant |

# Existing Constructive Solutions

## PDE configurations

Pure PDE, comprised of one or more detonation tubes an inlet and a nozzle

- Low inlet pressure at high altitude
- No detonation

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## Propulsion force generation

Direct use of the reactive jet exiting the PDC

Discharge of the PDC jet into a gas turbine

- High and oscillating jet temperature of the jet impinging the turbine blades

# Expected progress (1)

## Classical PDE design

- Detonation frequency of 10 Hz
- Mechanical limitation of the rotational speed
- The set of valves that open and close air, or air-fuel mixture admission in combustor suffer high wear, especially at high frequencies, and are subject to very high operating temperatures, and will induce pressure losses in the flow.

## Proposed solution

- Efforts towards increasing it
- Impact on the engine performance assess and minimized
- Valveless designs, based on carefully timed pressure gradients in the flow, are an obvious goal for the future PDC development

# Expected progress (2)

## Fuel supply system

- Needs to provide fuel in close correlation with the PDC operating frequency
- Continuous supply through the disk supporting the rotating PDCs.
- The disk will also include the ignition system
- Has the advantage of providing sufficient space to premix the air and fuel
- To achieve vaporization and possibly preheating in the case of liquid fuels
- By monitoring the pressure inside the combustor, feedback signal can be provided to ensure the correct synchronization

## Initiation of detonation wave

- Strongly dependent on the inlet conditions
- Use of very energetic spark, deflagration-to-detonation transition, or shock wave ignition

# Expected progress (3)

## Geometry of the PDE exit nozzle

- To increase overall engine efficiency combustors must provide the highest possible impulse on a direction other than along the combustor axis, the optimal direction with respect to the engine performances and constructive solution, as well as the minimization of pressure losses due to the deflection of the flow have to be studied.
- The addition of ejectors on the PDC nozzle should also be considered.

## PDC flow path

- Critical for the optimal detonation wave travel
- Stability and completeness of the supersonic combustion, strongly dependent on the combustor geometry, must also be optimized
- Of special interest is the production and emission of NOx. The high temperatures in the PDC favors the NOx production, while the very short residence time in the combustor will tend to decrease the effect, hence a quantitative approach will have to be used to determine NOx emissions
- Supersonic combustion models for finite rate kinetics numerical simulations, as well as the limitations of the existing models applied to detonations are still an open research topic

# Expected progress (4)

## Optimal compressor geometry

- Rotation of the downstream combustor
- Discontinuous discharge of the combustor shroud
- A high frequency PDC will alleviate the problem, but the effect on compressor stability remains to be assessed.
- Furthermore, since the combustion process is supersonic, the need to decelerate the flow upstream of the combustor disappears.
- Therefore, the presence of the compressor stator vanes may no longer be required, thus reducing the pressure losses during the passage between the rotating and fixed blading.

## The noise generated

- The effect of opposite phase pairs of PDCs and the optimal interference of the resulting sound waves needs to be investigated
- Also, the presence of detonation waves inside PDCs raises questions on the vibration levels of the new engine, which need further evaluation, understanding and solution finding

# Expected progress (3)

## Optimal fuel selection

- To allow the reliable initiation of the detonation wave, is also an open research field
- Most of the research studies carried out up to the present focus on gaseous fuels
- Experimental studies conducted on PDCs using liquid fuels (kerosene) have been reported in recent years
- The main problems when considering liquid fuels for PDC are the increased difficulty to initiate the detonation and the required very high mixing velocity of the air and fuel to be supplied to the combustor

## The specific fuel consumption

- Lower than in the case of a PJE
- By reducing the overall engine weight, optimizing the supersonic combustion process, and maximizing the engine power, the overall fuel consumption can be further minimize

## Novel materials

- Able to withstand the high temperatures in the PDC, together with the mechanical solicitations (mainly centrifugal load and vibrations) to bring the engine concept from a breakthrough technology to a market ready product

# Project Objectives (1)

- Given the complexity of the task, and the limited resources, the its scope is limited and does not try to tackle all the problems raised by the new engine concept.
- Instead, the main goal of the project is to prove the functionality and feasibility of the concept, opening the road towards developing a mature technology over the next 50 years.
- The most important result expected from the proposed project is to demonstrate, both numerically and experimentally, that the power provided by the rotating PDCs can provide the energy to accelerate the compressor to the speed required for its design performance, with sufficient excess energy to power up the aircraft.
- A second achievement is expected to be the practical realization of a high frequency, self supporting ignition PDC.

# Project Objectives (2)

- Combustor inlet will be valve free, and the solution selected to control the inlet must be proven to prevent the detonation wave to propagate upstream. A high frequency PDC is expected to be compact, both in diameter and in length, allowing significant reduction in engine dimensions and weight.
- The constant volume cycle is of higher efficiency than the classical Brayton cycle. Due to the elimination of the classical engine turbine, the maximum temperature limitation will be removed, thus allowing an overall increase in the engine performance and efficiency. The project aims at demonstrating the increase in theoretical cycle efficiency.
- Finally, the project will provide an integrated solution for the proposed concept, validated through numerical simulation, and laying the foundation for building a demonstrator engine concept in the future.

# Thank you for your attention!

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