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Thrust performance of air-breathing pulse detonation engine at subsonic and supersonic flight at different altitudes.

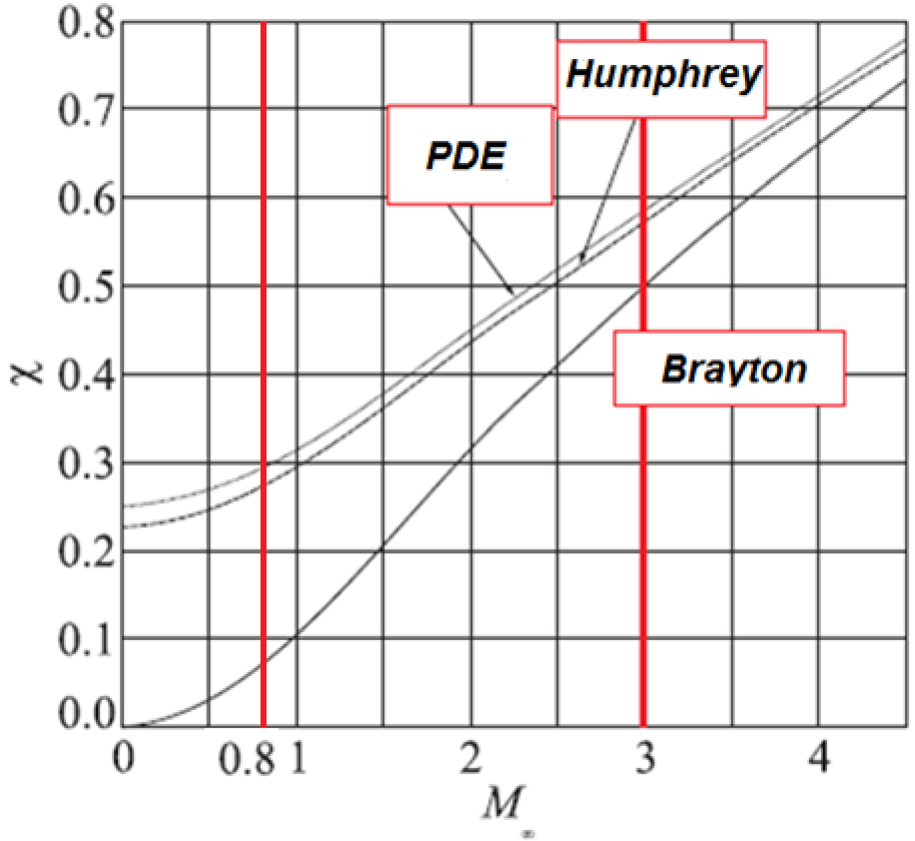
A. E. Zangiev, *V. S. Ivanov, S. M. Frolov*

N. N. Semenov Institute of Chemical Physics Russian Academy of Sciences.

Overview

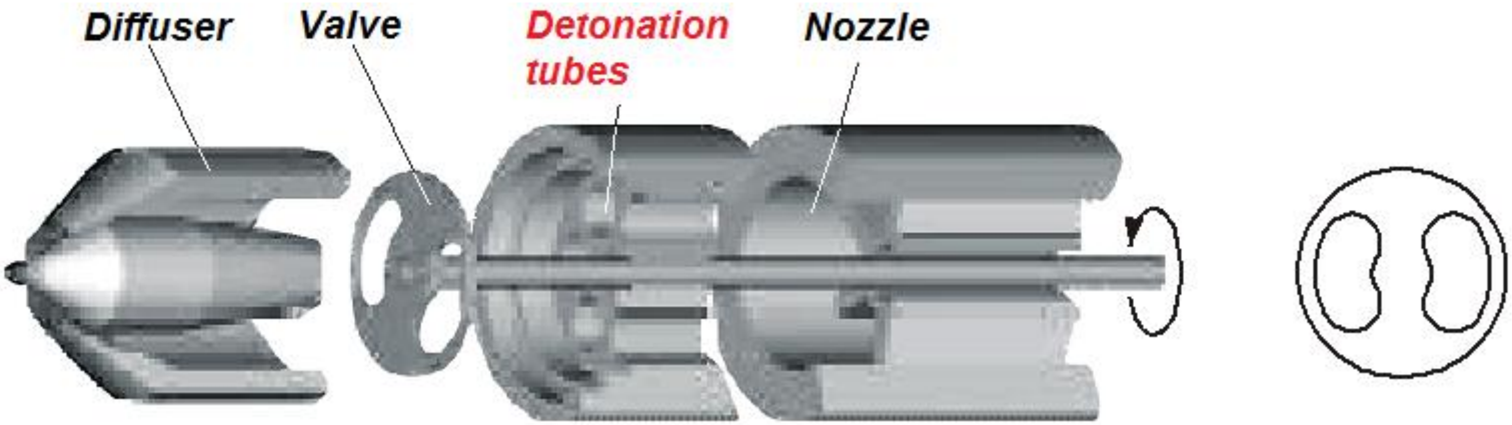
- Introduction
- Objectives
- Scheme of PDE
- Mathematical model
- Specific impulse calculation results
- Comparison of results
- Conclusions

Introduction:
Thermodynamic efficiency



*Zel'dovich, 1940 +

Pulse detonation engine (PDE) for aircrafts



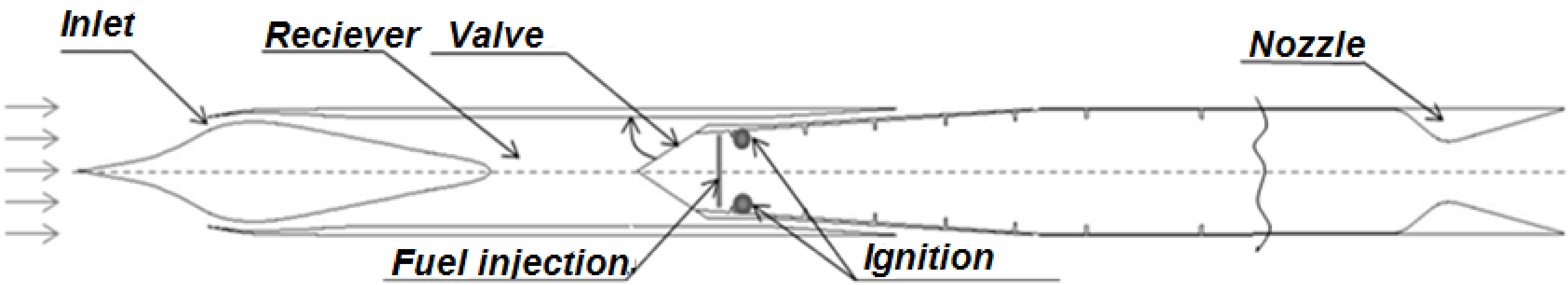
Objectives

- **Thrust performance calculations of air-breathing pulse detonation engine with DDT in subsonic and supersonic flight conditions at different altitudes.**

- **Prove the feasibility of the pulse detonation cycle workflow in PDE in subsonic flight with mach number 0.8 and supersonic flight with mach number 5.**

Scheme of PDE

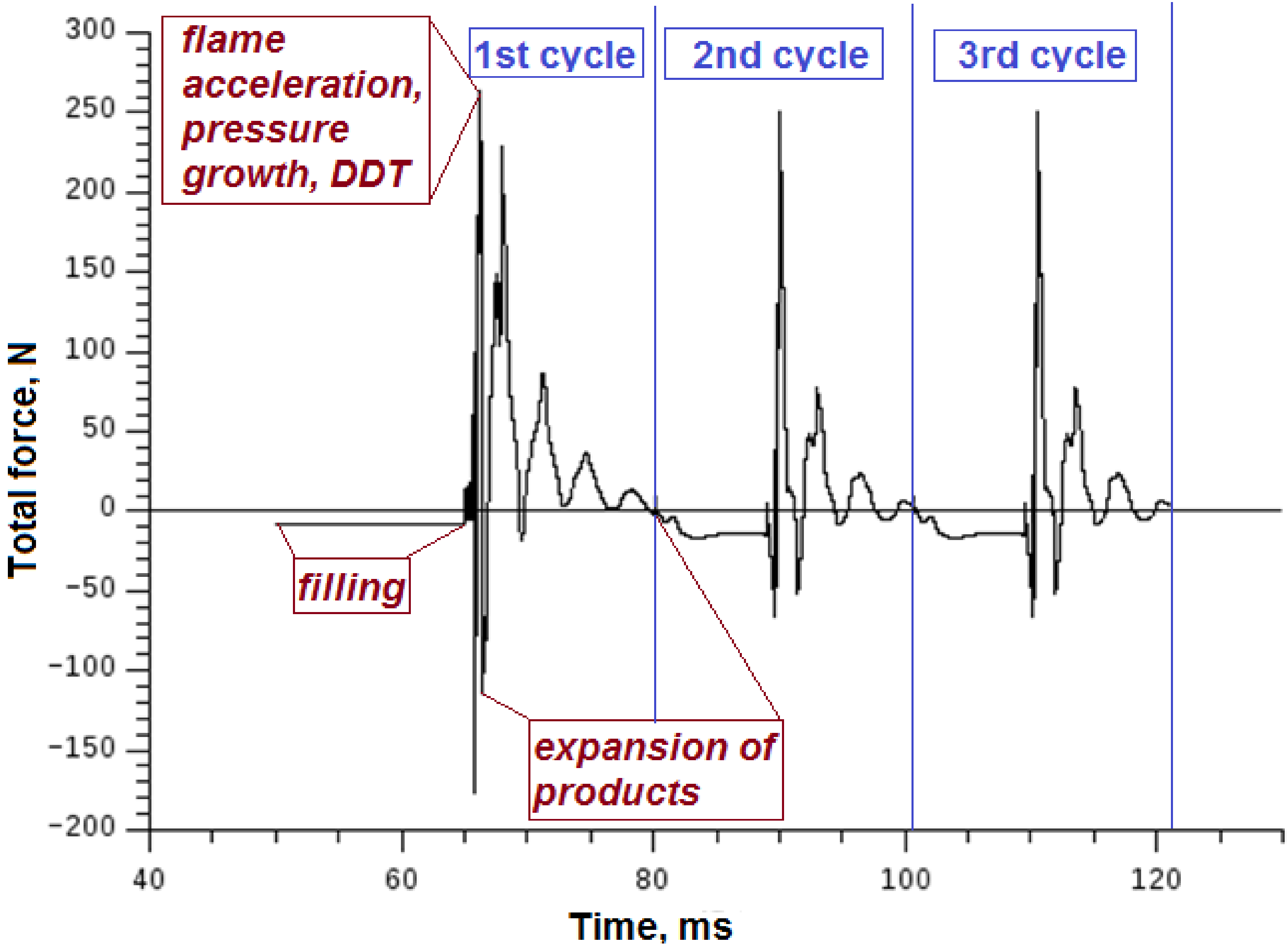
M = 3



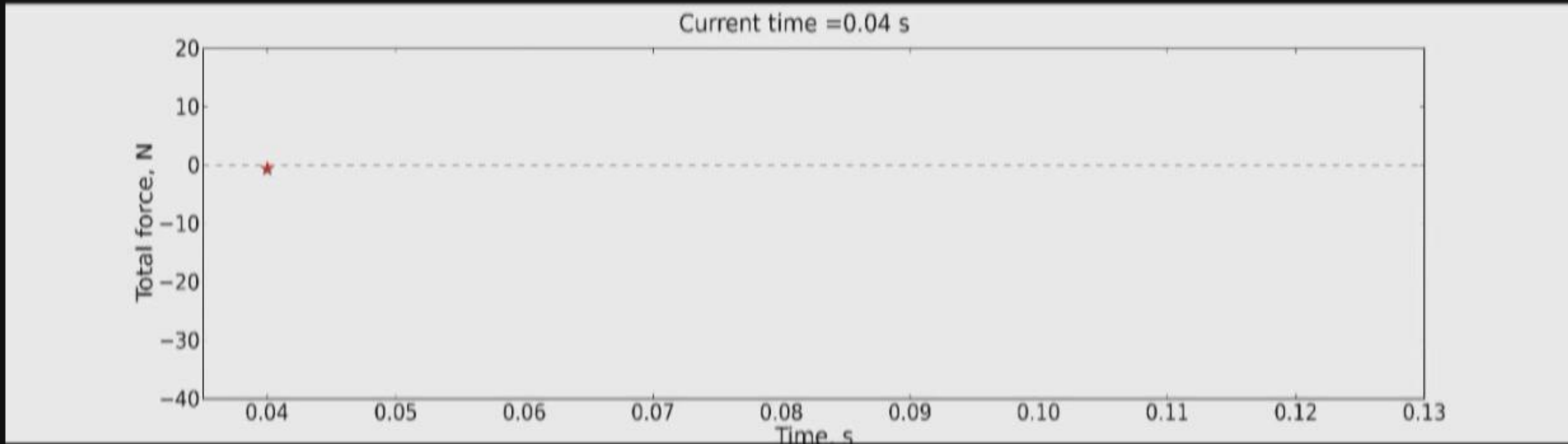
Diameter: 83 mm
Lenght: 2 m
Fuel: propane

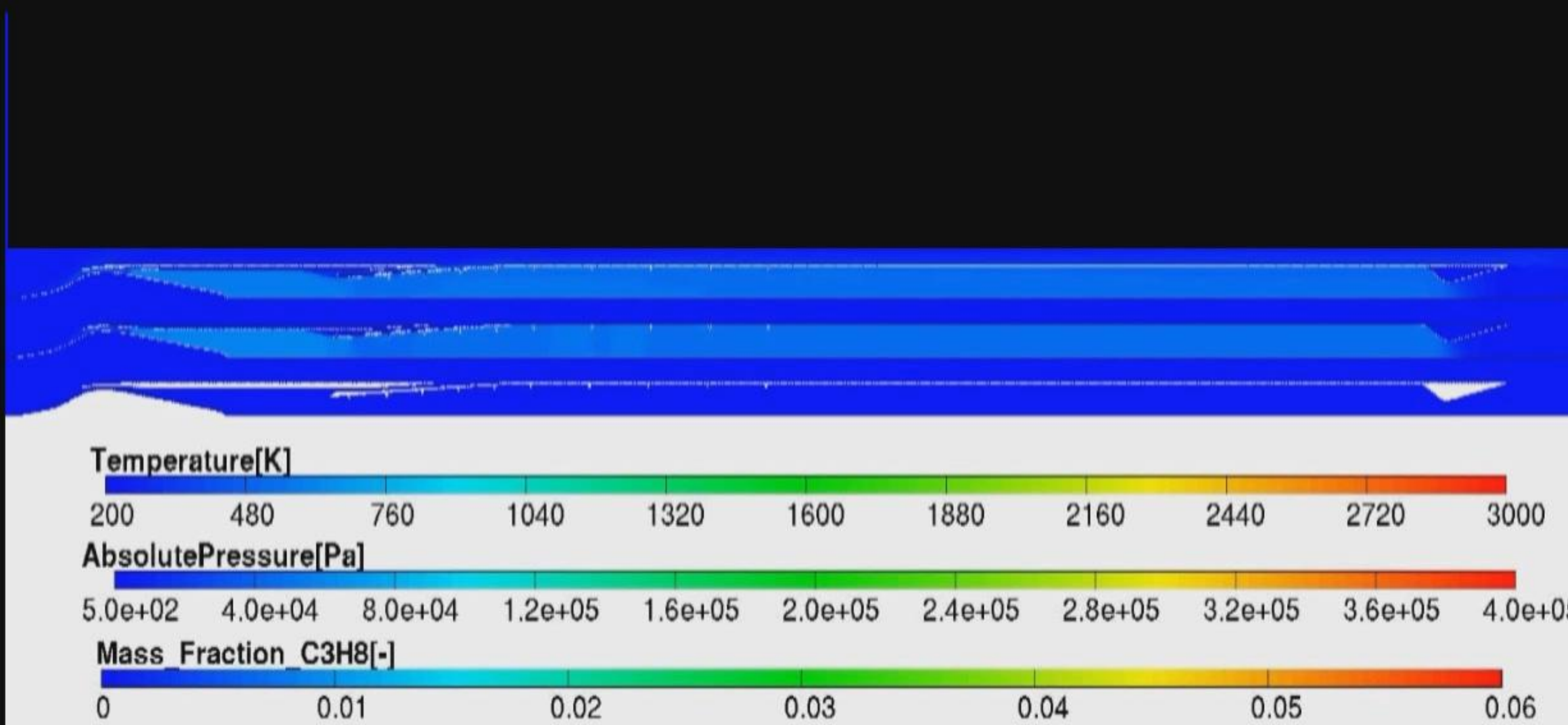
Mathematical model

- **Unsteady Reynolds-Averaged Navier-Stokes (URANS) equations;**
- **Continuity and energy equations for a multicomponent reactive mixture;**
- ***k-ε* turbulence model;**
- **Flame tracking;**
- **Particle method;**
- **Initial and boundary conditions.**



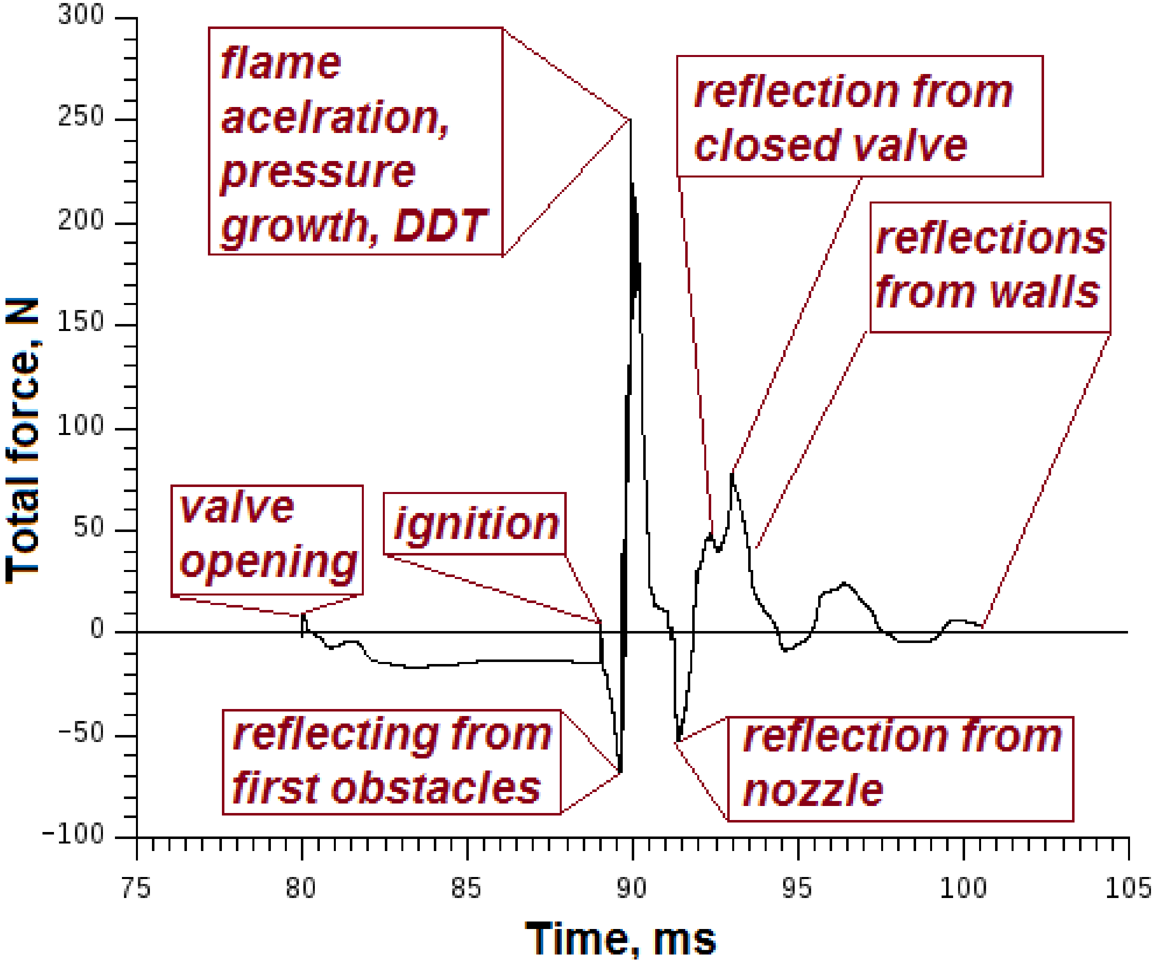
Altitude –8km.


Current time =0.04 s
Total force, N
20
10
0
−10
−20
−30
−40
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
Time, s


Temperature[K]
200 480 760 1040 1320 1600 1880 2160 2440 2720 3000
AbsolutePressure[Pa]
5.0e+02 4.0e+04 8.0e+04 1.2e+05 1.6e+05 2.0e+05 2.4e+05 2.8e+05 3.2e+05 3.6e+05 4.0e+05
Mass_Fraction_C3H8[-]
0 0.01 0.02 0.03 0.04 0.05 0.06

Specific impulse:

$$I_{sp} = \frac{F}{g * \dot{m}}$$



F - thrust in one cycle
(with drag force)

g - gravitational acceleration

$\dot{m}$ - fuel mass flow for one cycle

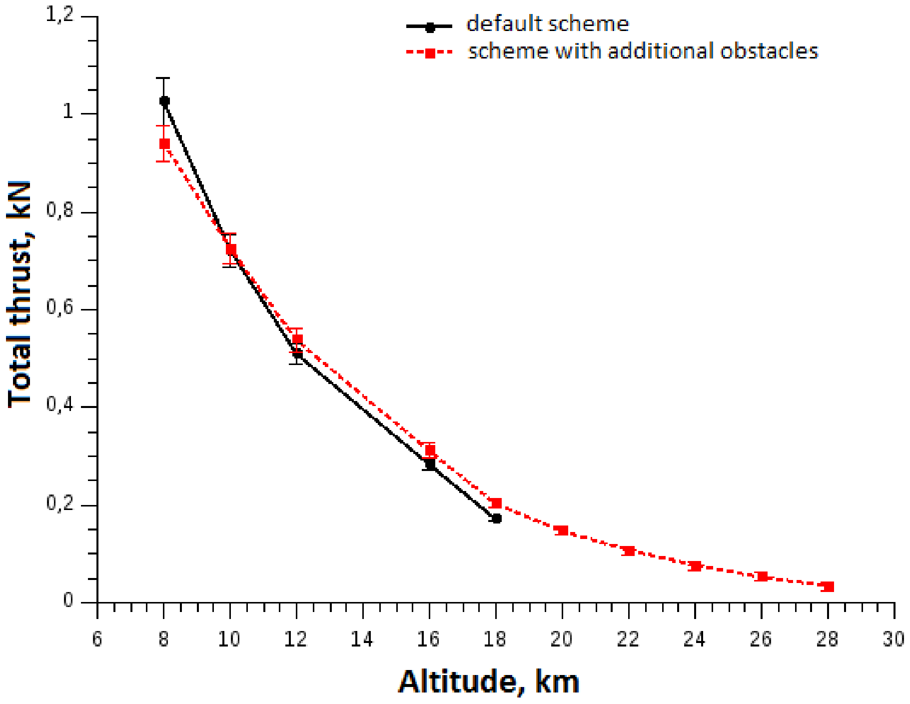
Specific impulse calculation results

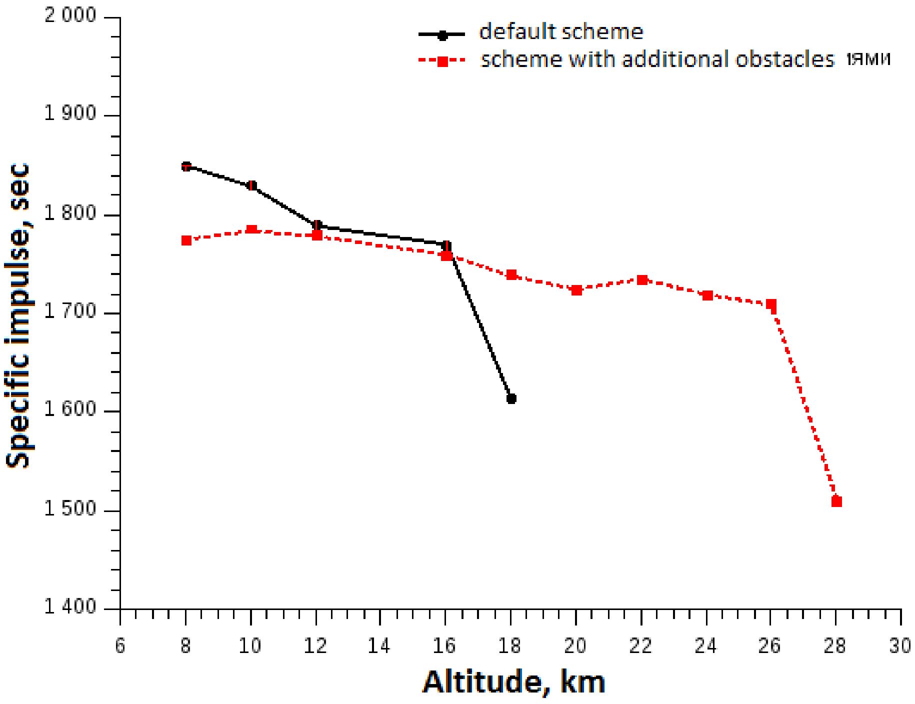
Z, km	*P, MPa*	*Ta, K*	*τ, ms*	*f*, Hz	*P*, MPa*	*F, N*	*m', g/s*	*Isp, s*
8	0.036	236.2	20.5	**49**	0.439	**255**	56	**1850**
10	0.027	223.3	20	**50**	0.31	**204**	40	**1830**
12	0.0194	216.7	20	**50**	0.243	**147**	35	**1790**
16	0.010	216.7	20	**50**	0.175	**84**	17	**1770**
18	0.0075	216.7	18.5	**54**	0.073	**8**	13	**1615**
20	**0.0055**	**216.7**	**No DDT**					

Specific impulse calculation results

Z, km	*P, MPa*	*Ta, K*	*f, Hz*	*P*, MPa*	*F, N*	*m', g/s*	*Isp, s*
8	0.036	236.2	**50**	0.406	**266**	54	**1775**
10	0.027	223.3	**50**	0.312	**228**	41	**1790**
12	0.0194	216.7	**50**	0.232	**176**	31	**1790**
16	0.010	216.7	**50**	0.159	**121**	15	**1760**
18	0.0075	216.7	**50**	0.091	**63**	12	**1720**
20	0.0055	216.7	**50**	0.068	**45**	9	**1735**
22	0.004	216.7	**50**	0.048	**32**	7	**1720**
24	0.003	220.6	**49**	0.032	**21**	4	**1710**
26	0.002	222.7	**49**	0.023	**14**	3	**1710**
28	0.0016	224.7	**53**	0.015	**4**	2	**1510**

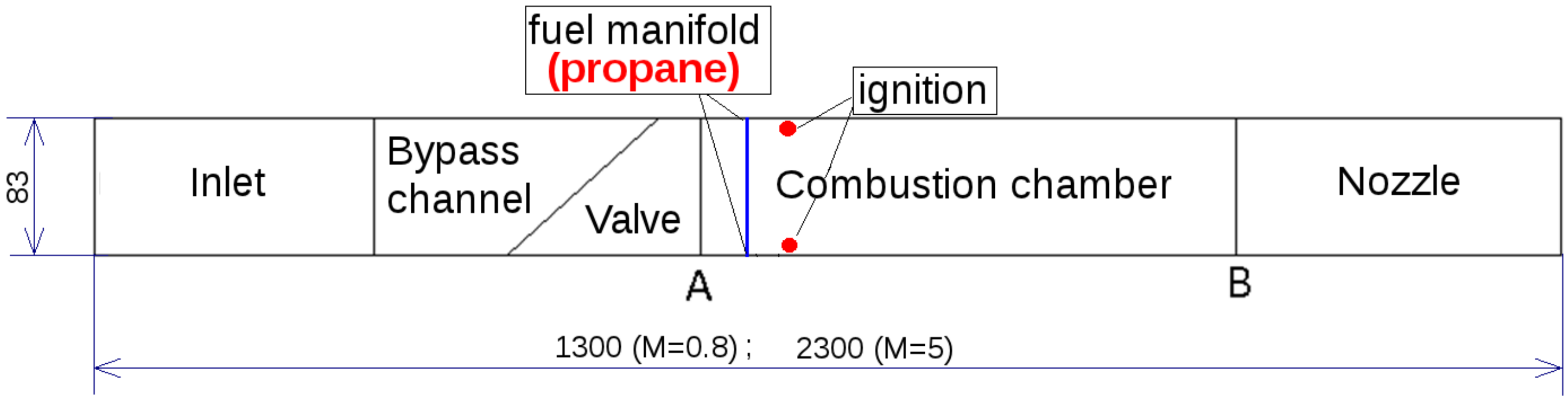
Specific impulse calculation results

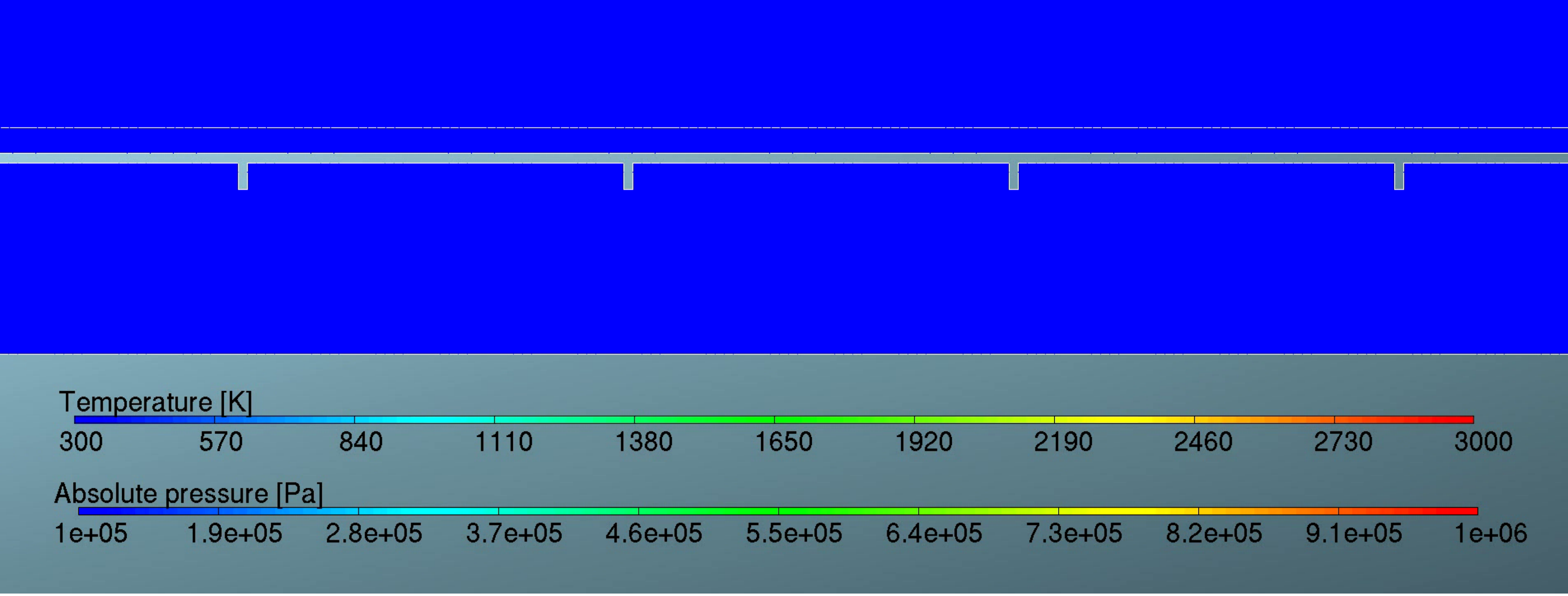




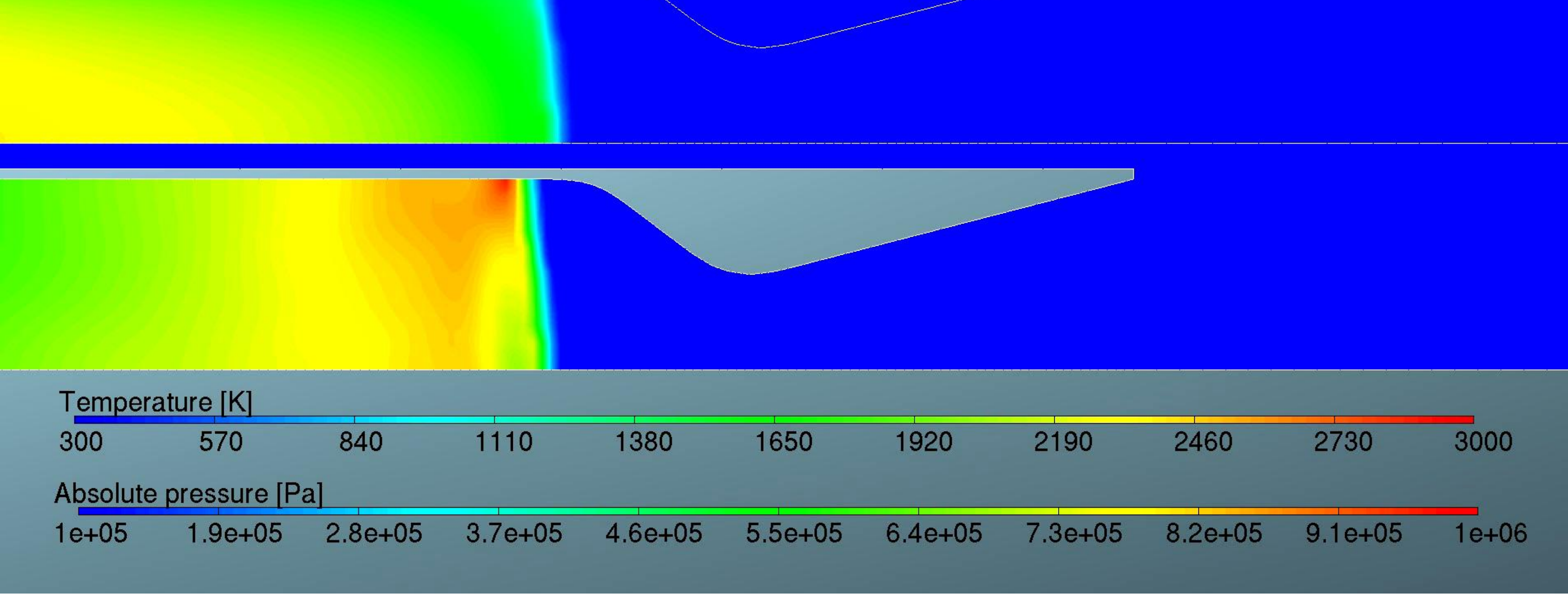
Scheme of PDE for subsonic flight M=0.8 and supersonic flight M=5

M = 0.8
M = 5





Temperature [K]
300 570 840 1110 1380 1650 1920 2190 2460 2730 3000
Absolute pressure [Pa]
1e+05 1.9e+05 2.8e+05 3.7e+05 4.6e+05 5.5e+05 6.4e+05 7.3e+05 8.2e+05 9.1e+05 1e+06


Temperature [K]
300 570 840 1110 1380 1650 1920 2190 2460 2730 3000
Absolute pressure [Pa]
1e+05 1.9e+05 2.8e+05 3.7e+05 4.6e+05 5.5e+05 6.4e+05 7.3e+05 8.2e+05 9.1e+05 1e+06

Comparison of results

Z, km	P, MPa	T_a, K	f, Hz	R, N	I_{sp}, s	C_p	R_{sp}, kN/(kg/s)	C_{sp}, kg/(N·h)	m'_f, g/s
Flight with Mach number 0.8									
0	0.101	288.2	75	241	1320	0.88	0.82	0.28	18
0.5	0.095	284.9	70	228	1340	0.89	0.85	0.28	17
Flight with Mach number 3									
16	0.010	216.7	50	313	1760	0.87	1.1	0.21	15
Flight with Mach number 5									
28	0.0016	224.5	55	35	1620	0.21	1.02	0.22	2

Conclusions

• Method for analysis of PDE operation process in subsonic and supersonic flight at different altitudes was developed. Calculations for Mach 0.8, 3, 5 flight speed were made.

• In flight with Mach number =3, 18 km is the limit height for default configuration. At altitude higher than 18 km there is no DDT. By adding additional obstacles , we increase limit height to 28km.

• Proved the feasibility of cyclic workflow in PDE in subsonic and supersonic flight conditions with positive thrust.

Thank you for your attention