Technion – Israel Institute of Technology
Faculty of Mechanical Engineering
Internal Combustion Engine Laboratory

Improvement of Wankel engine performance at high altitudes

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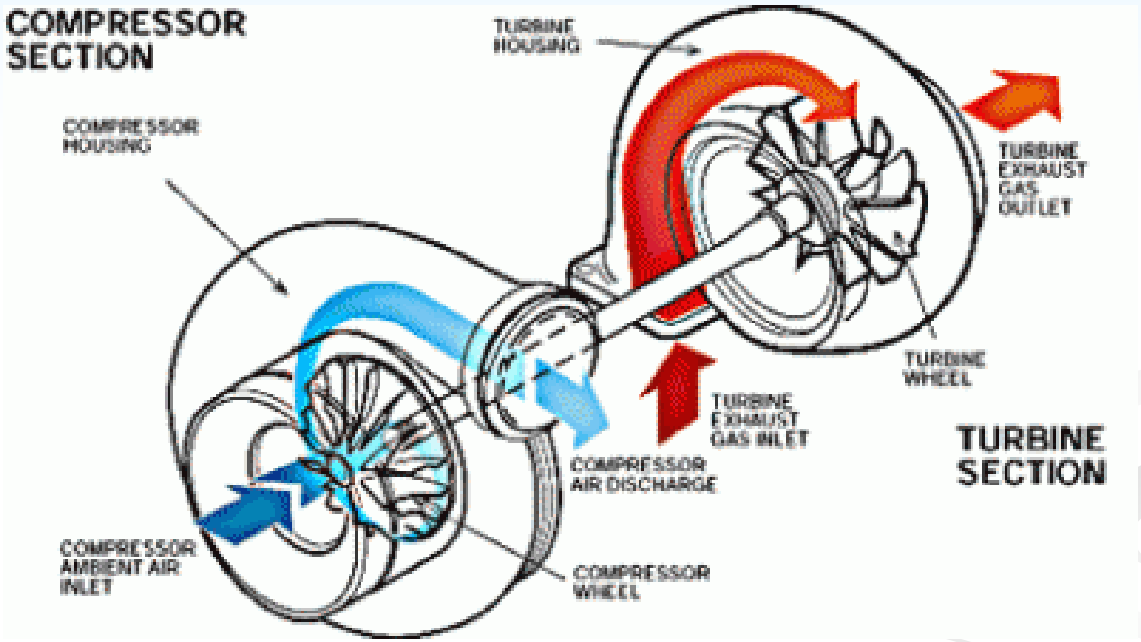
The problem

UAV engine's power drop under high-altitude flight conditions

One of Possible Solutions



Engine turbocharging

Main objectives

- Keeping a Wankel engine's rated brake power as constant as possible in the altitudes range between 0 and 15,000 feet
- Possible improvement of engine's efficiency
- Selection of a turbocharger currently available on the market for Wankel engine supercharging

Simulation approach

- Application of the GT-POWER software initially intended for modeling reciprocating piston engines for simulating a rotary Wankel engine

Main differences between Wankel and piston engines affecting their performance

- **Difference in patterns of working chamber volume and surface change with the shaft angle**
- **Differences in the heat transfer conditions**
  - **‘Hot’ and ‘cold’ stator zones of the Wankel working chamber surfaces are separated contrary to a piston engine**
  - **Charge rotational movement of Wankel working chamber**
- **Differences in combustion patterns**
  - **Unfavorable shape of Wankel working chamber - higher surface/volume ratio**
  - **Larger relative value of crevice volumes**

Development of a piston-to-Wankel engine geometric similarity criteria

- ✓ Displacement equality
- ✓ Compression ratio equality
- ✓ Identical behavior of working chamber volume dependence on angle of shaft rotation
- ✓ Identical behavior of working chamber surface-to-volume ratio change vs. angle of shaft rotation
- ✓ Identical behavior of intake and exhaust ports discharge coefficients vs. angle of shaft rotation

The method

- Compilation of the virtual reciprocating piston engine, geometrically similar to the considered Wankel engine
- Modifying the Wiebe equation used for simulation of the fuel combustion by taking into account the peculiarities of the combustion process in a Wankel engine
- Application of the modified relationship between Nusselt, Prandtl and Reynolds numbers for calculation of the heat transfer coefficient;
- Virtual blowing of the intake and exhaust ports for calculation of their discharge coefficients.

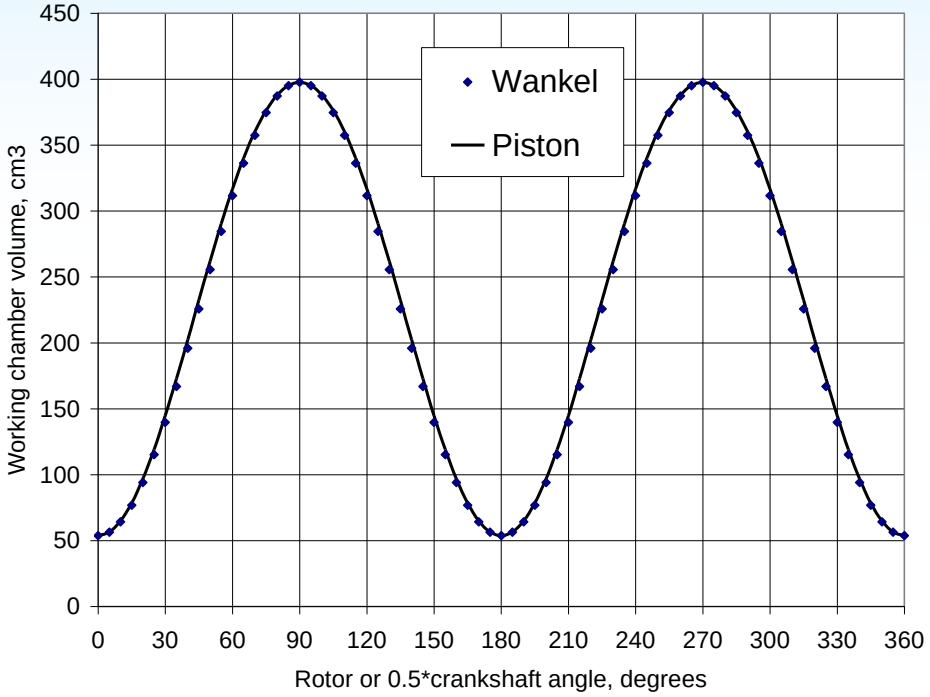
Simulated Wankel engine

- Naturally aspirated, spark ignition, single-rotor
- Rated shaft speed – 8,100 rpm
- Rated brake power – 70 HP
- Displacement of each working chamber – 344cc

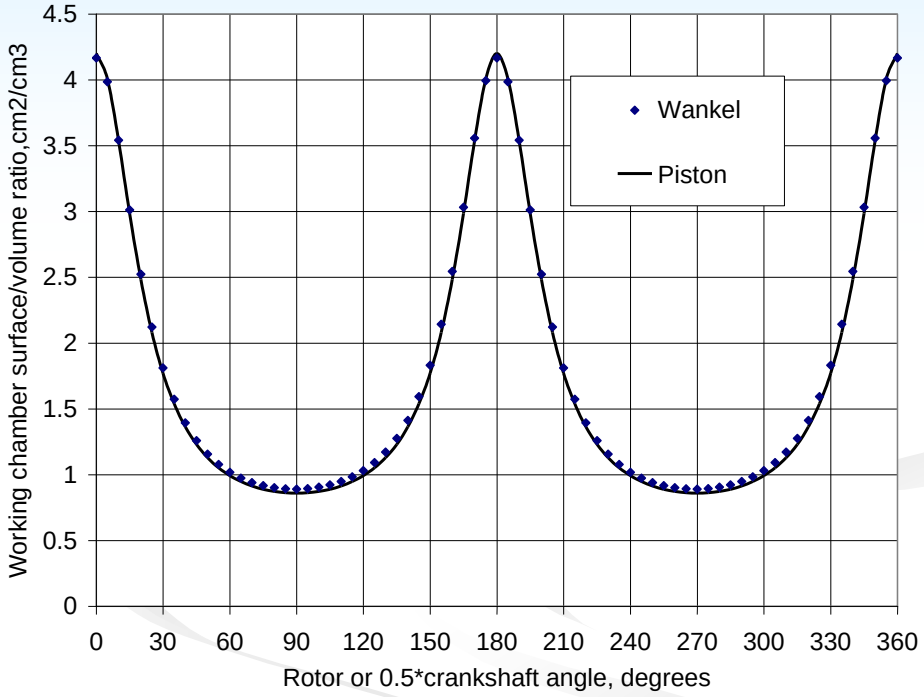
Parameters of the virtual piston engine

Designation	Parameter	Value
z	Number of cylinders	3
ε	Compression ratio	7.6
B	Bore, mm	118.6
S	Stroke, mm	31.2
R	Crank radius, mm	15.6
L	Conrod length, mm	220
V_d	Displacement, cm^3	1032

Geometric similarity

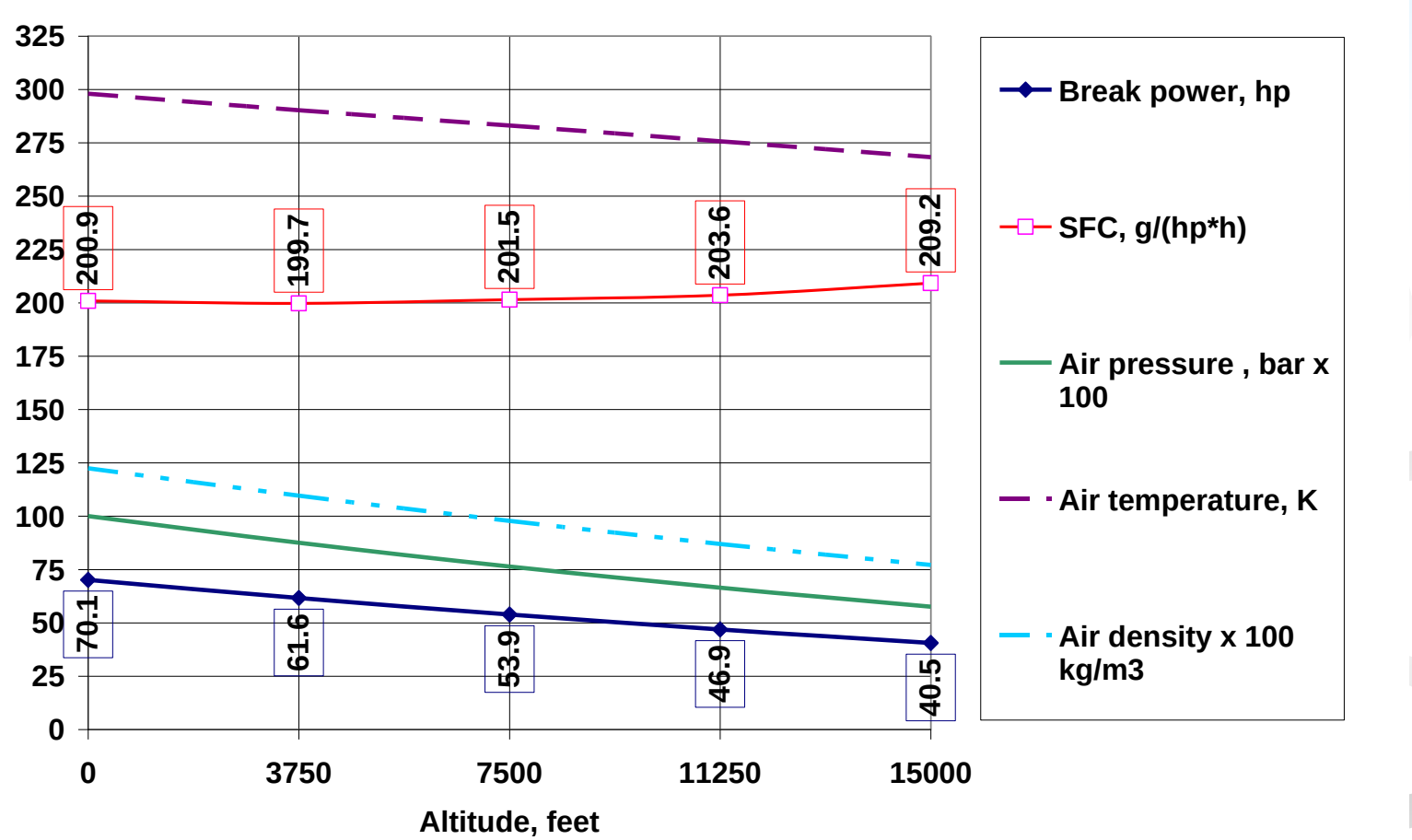


Working chamber volume



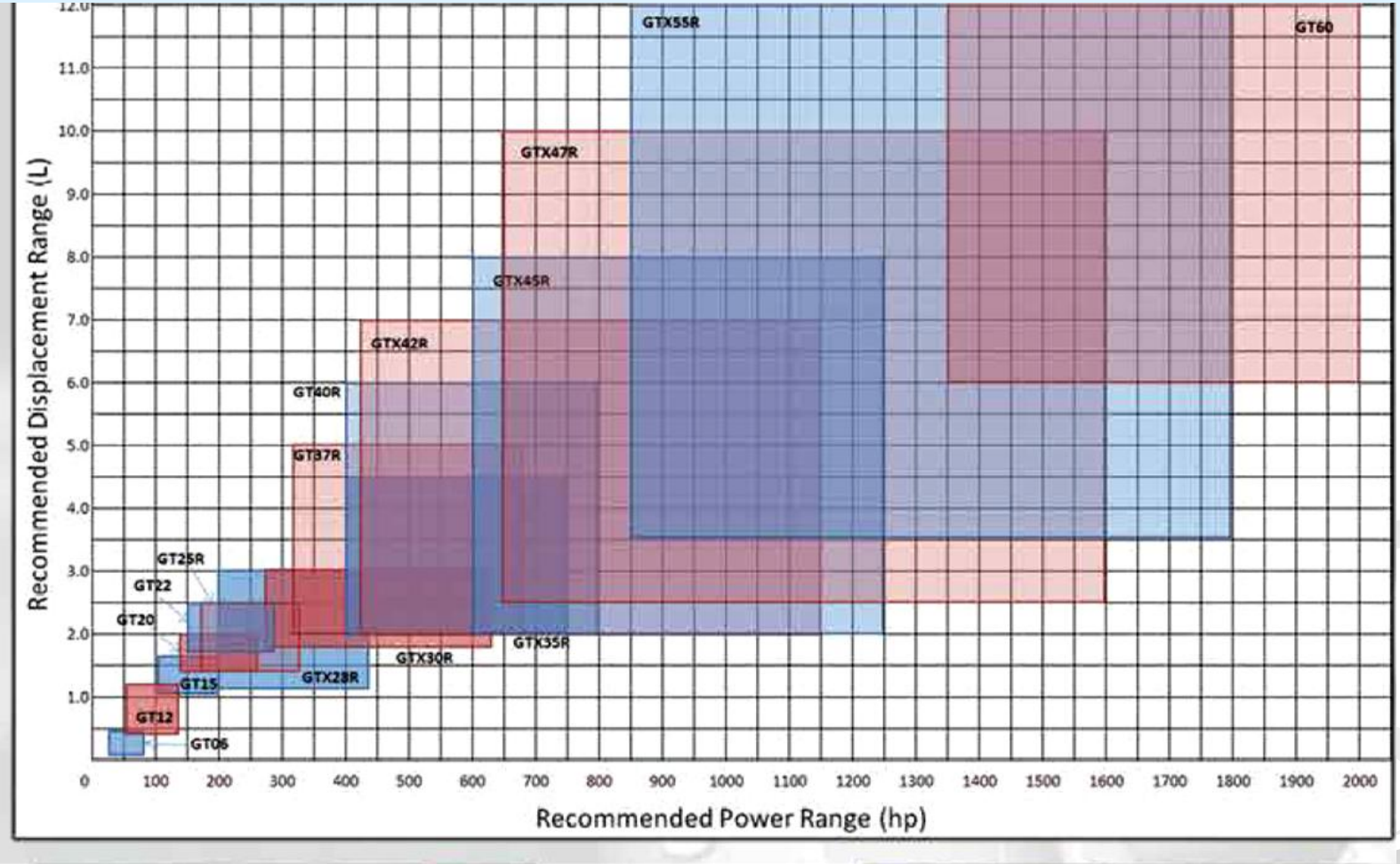
Working chamber surface/volume ratio

Altitude performance of the naturally aspirated Wankel engine



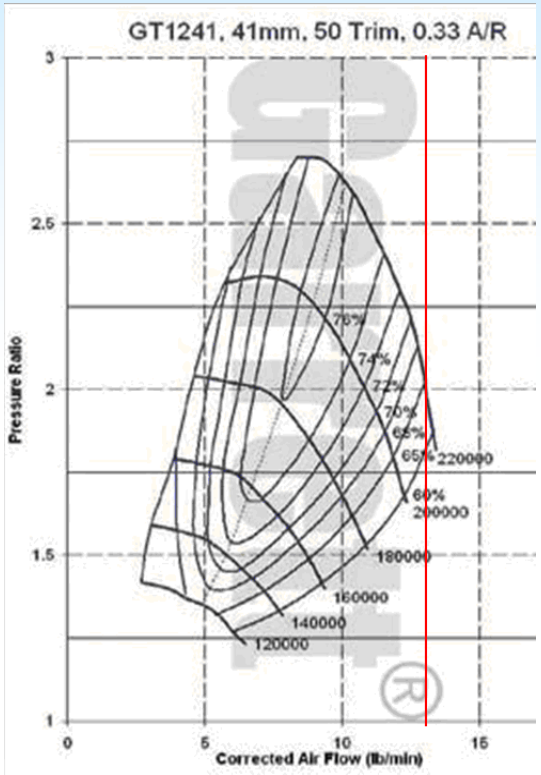
At flight altitude of 15,000 feet the engine's power drops by a factor of 1.7

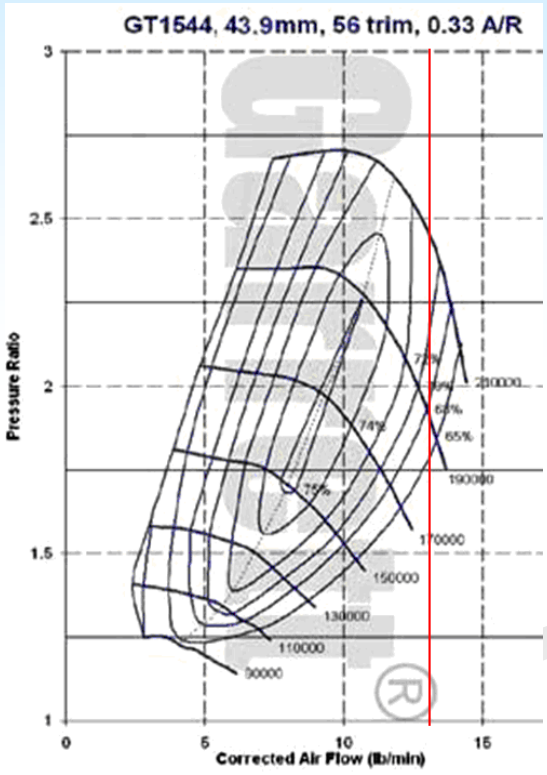
Turbocharger selection

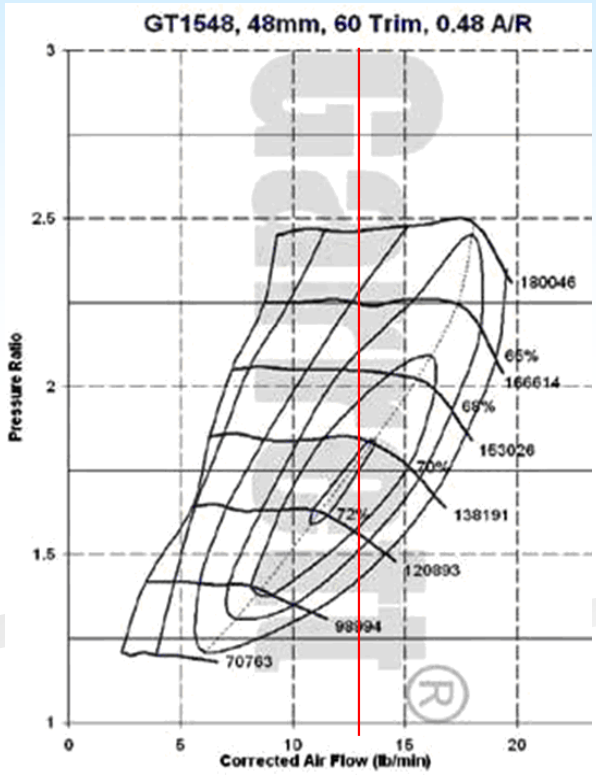


Garret GT12 and GT15 turbochargers were selected for further consideration

Turbocharger selection



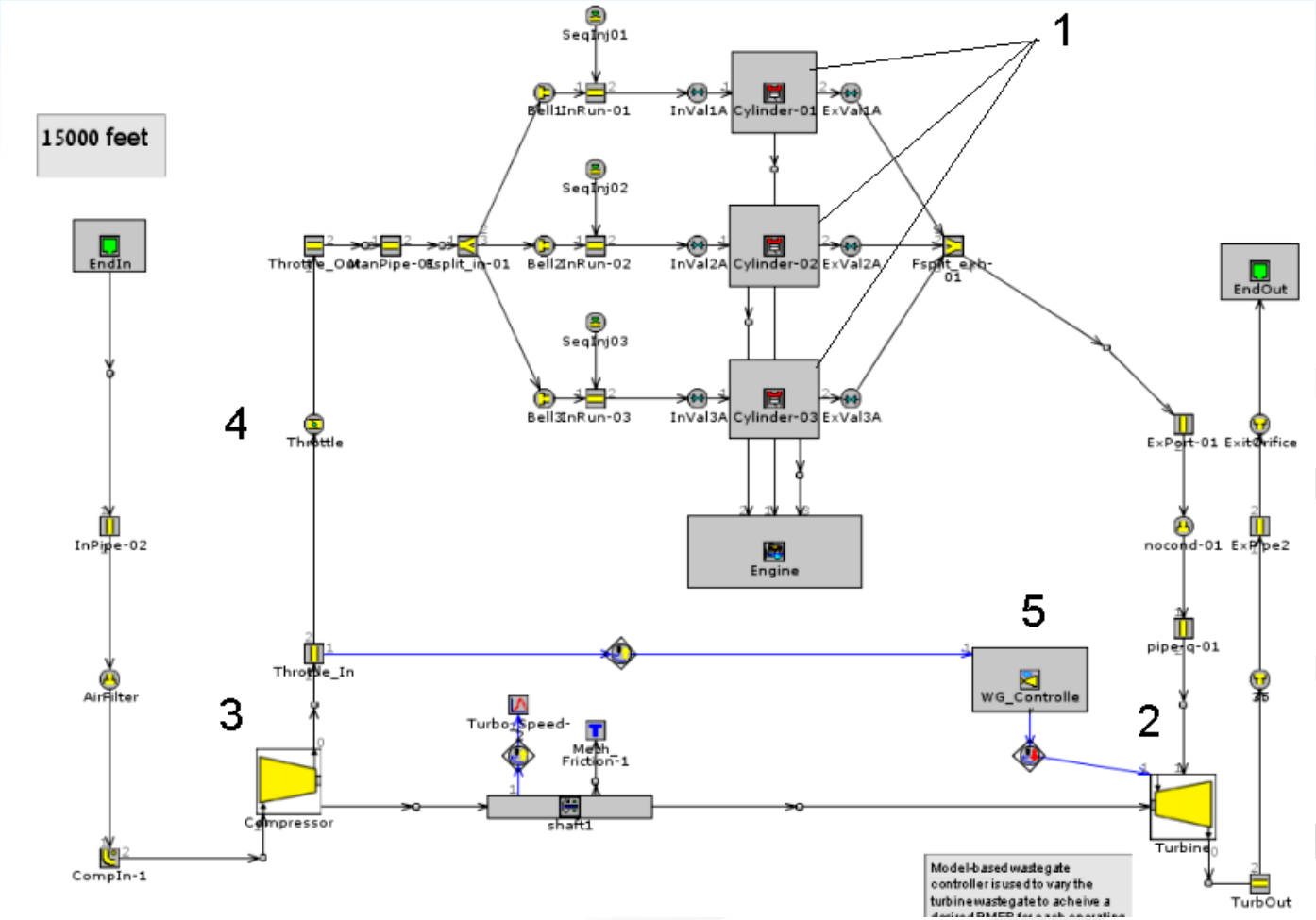




The required air flow rate is marked by red line

Turbocharger Garret® GT1548 was finally selected

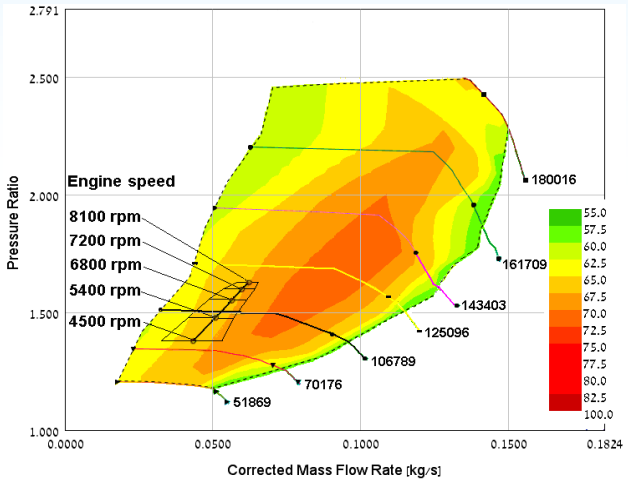
Simulation model of the turbocharged engine in the GT-Power



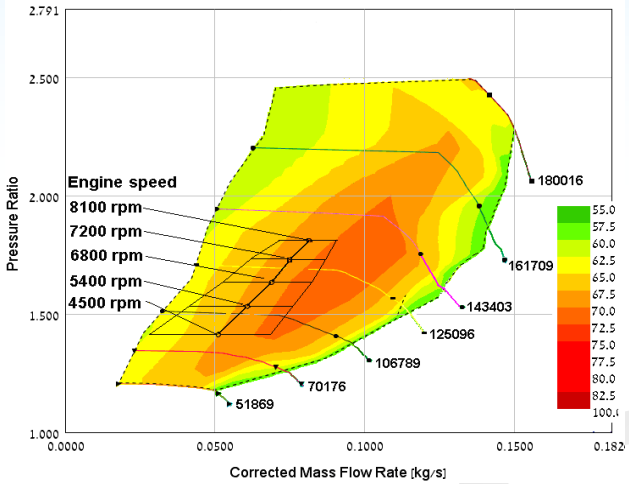
1 – cylinders; 2 – turbine wheel; 3 – compressor wheel; 4 – throttle; 5 – wastegate controller

Altitude performance prediction

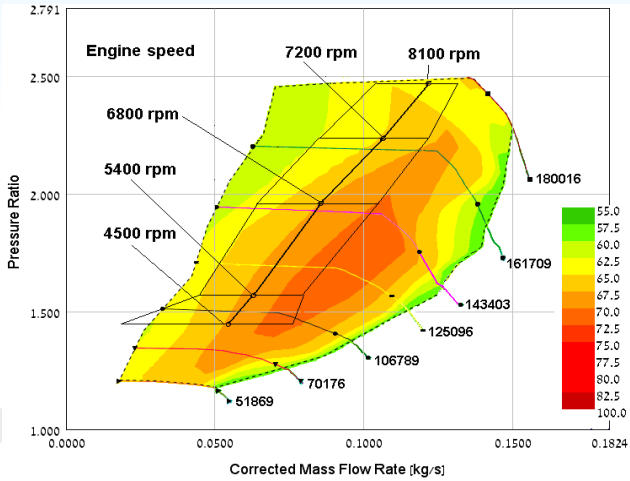
throttling the intake manifold



Sea level



7,500 feet

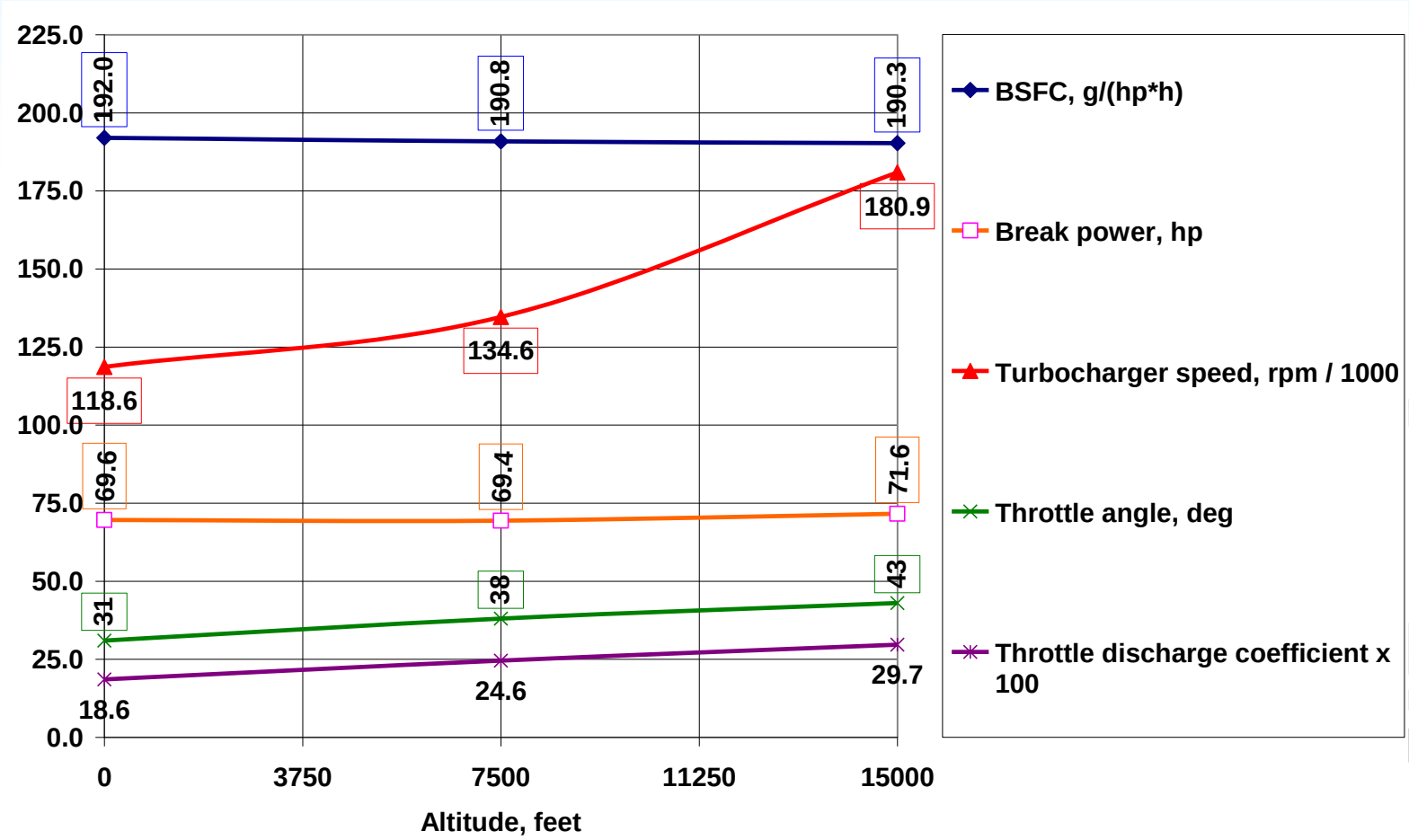


15,000 feet

- ✓ **At altitude 15,000 feet and 4500 rpm the compressor enters into the surge zone**
- ✓ **At altitude 15,000 feet and 8100 rpm the compressor works very close to its maximal operation speed – 180,000 rpm**

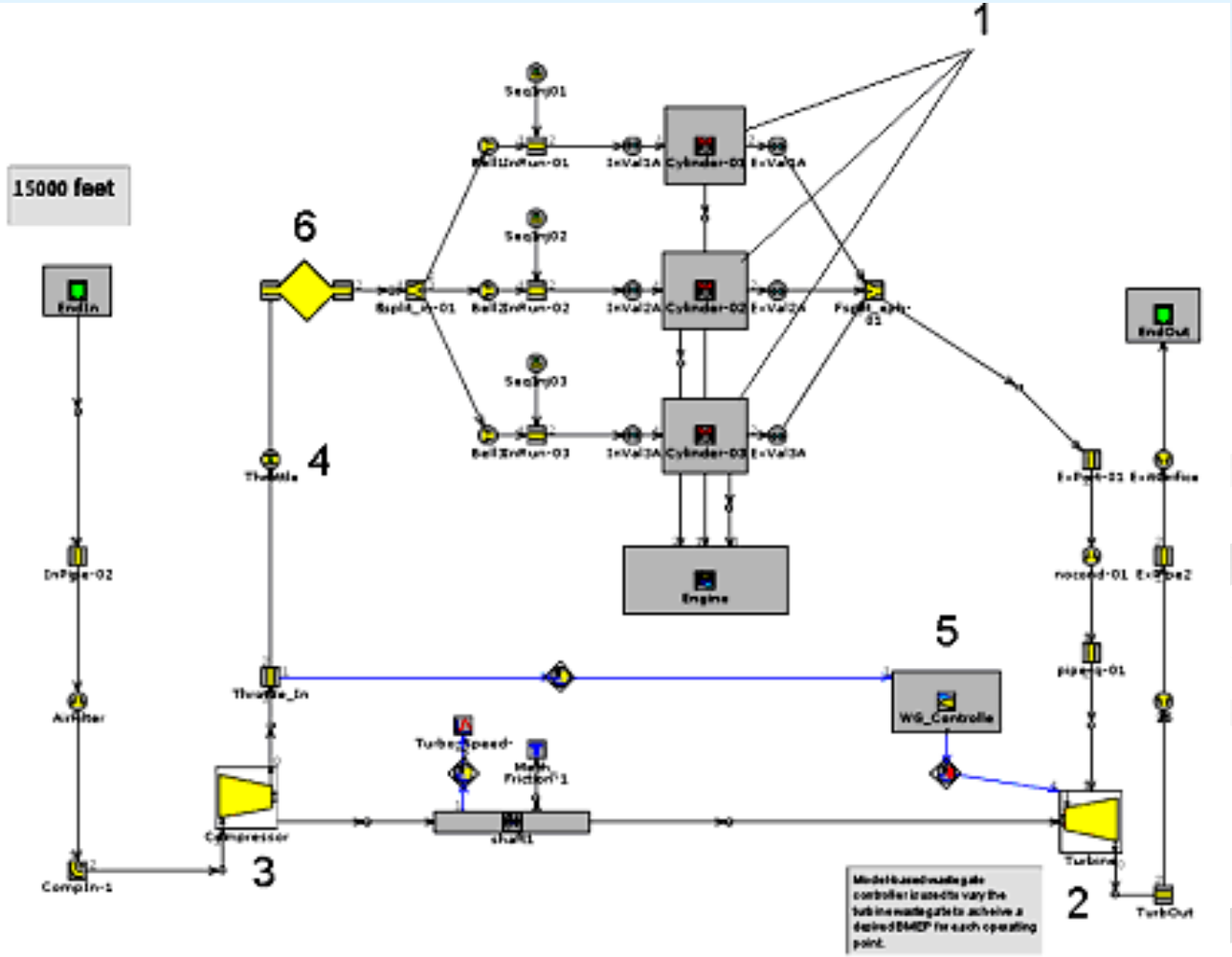
Altitude performance

throttling the intake manifold



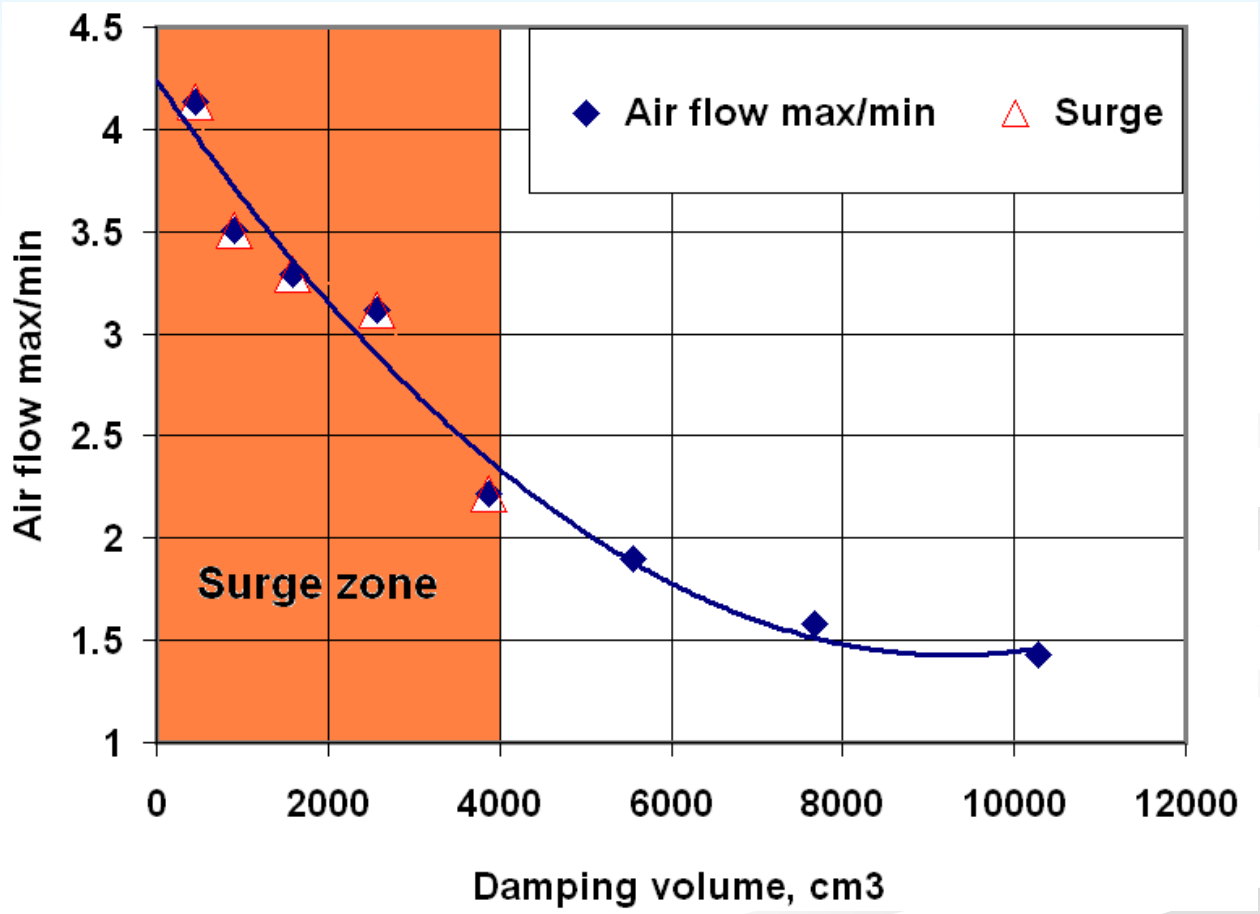
Altitude performance prediction

Damping volume in the intake manifold



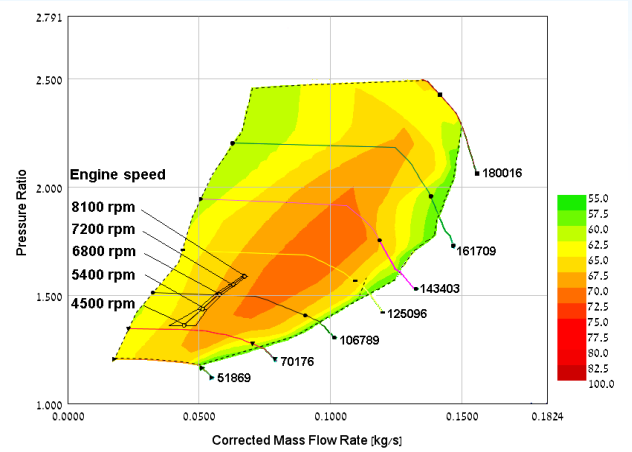
1 – cylinders; 2 – turbine wheel; 3 – compressor wheel; 4 – throttle; 5 – wastegate controller; 6 - damping volume

Dependence of the air flow swing on the value of the damping volume

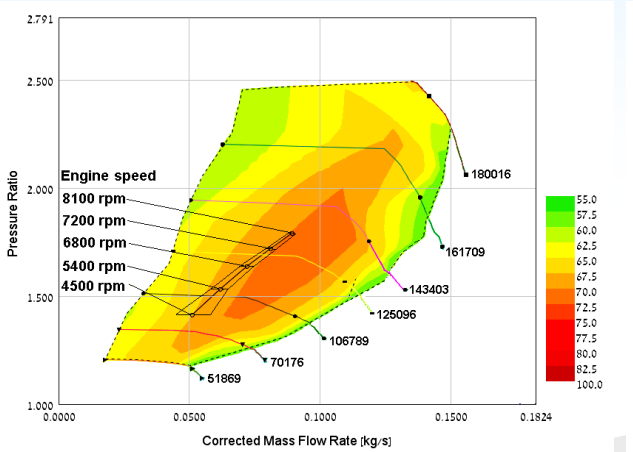


Altitude performance prediction

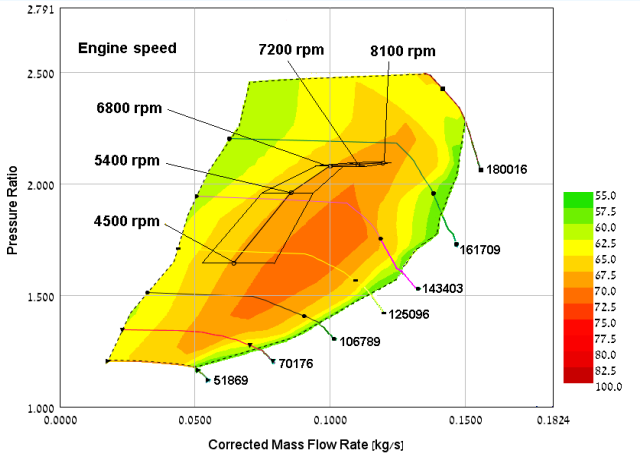
Damping volume in the intake manifold



Sea level



7,500 feet

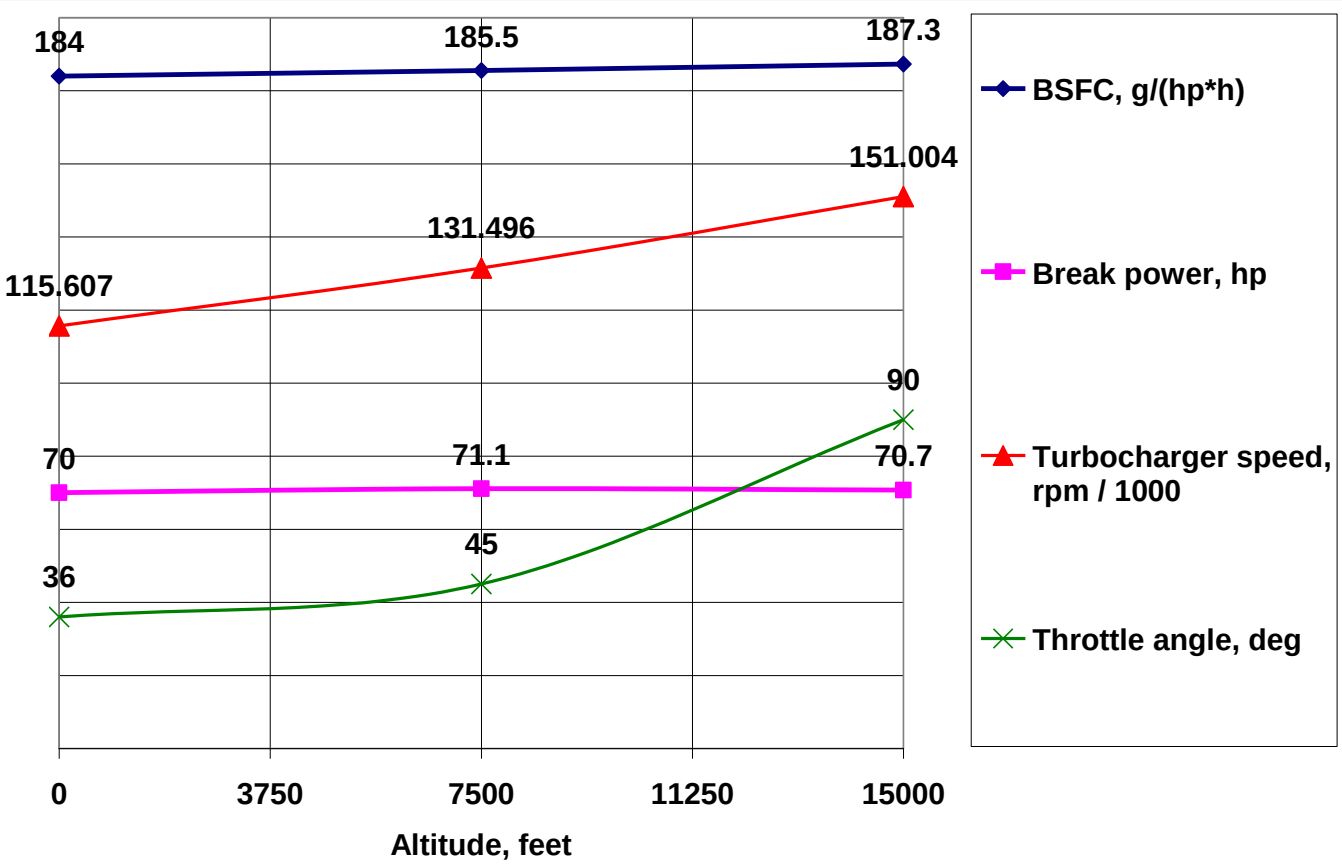


15,000 feet

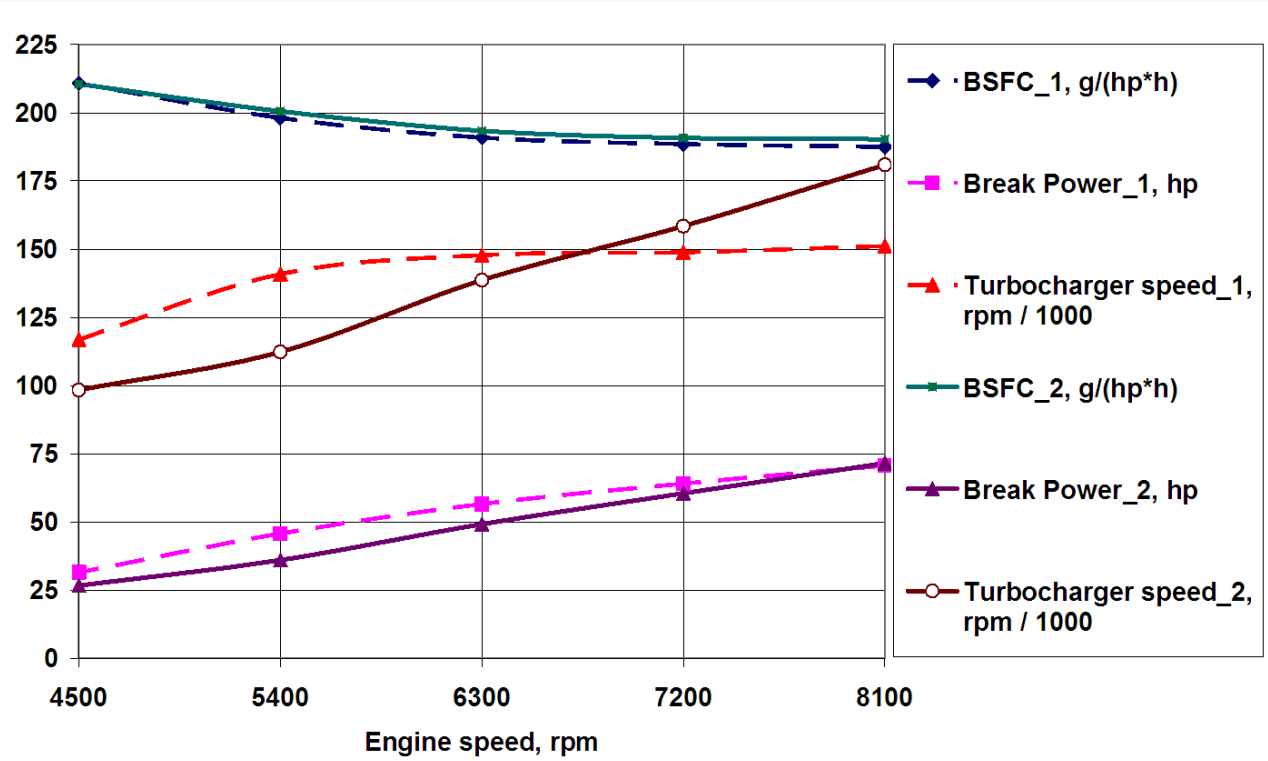
- ✓ **No surge danger**
- ✓ **Turbocharger operates far from its maximal operation speed**

Altitude performance

Damping volume in the intake manifold



Comparison of the engine performance with different methods of pressure waves suppression - *Altitude 15,000 feet*



1 – the damping volume
2 – the throttle screening

- ✓ **Better specific fuel consumption by about 1.5%**
- ✓ **Turbocharger operates far from its maximal operation speed**
- ✓ **Engine power under partial loads is up to 27% higher**

Conclusions

✓A modeling was carried out by using the GT-POWER software. The method of compiling a virtual piston engine was applied

✓At the flight altitude of 15,000 feet Wankel engine's power drops by a factor 1.7

✓ Performance predictions of the turbocharged engine confirmed a possibility of maintaining its power at all altitudes up to 15,000 feet, but revealed presence of a strong pressure wave process in the engine's intake manifold

✓ Two different methods of the compressor wheel protection from impact of the intake air pressure waves were studied: throttling and dumping volume use

✓ Very important advantage of the damping volume method is a reduction of the turbocharger's speed by about 17% under maximal power and higher engine efficiency by about 1.5% practically under entire engine speed range

✓ Expected increase of the supercharged engine weight may be assessed as 6 kg.

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Thank you!

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