

# ICE Turbochargers Failures

## and Some Features of the Study of Their Causes Using the Fault Tree Analysis



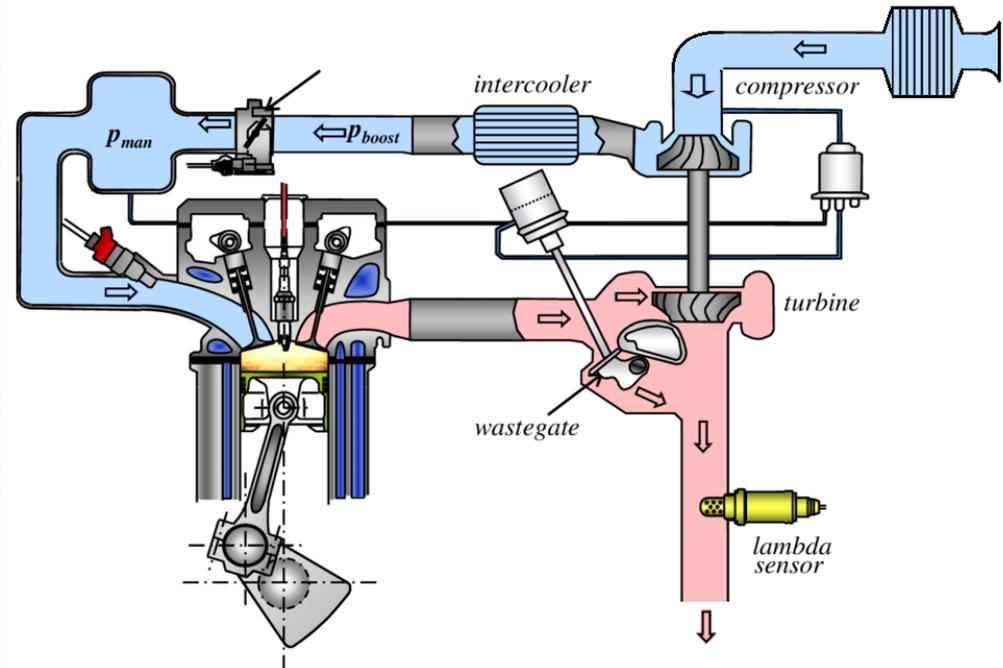
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## Turbocharging technology for ICE:

- ❖ **100 years ago** - the first use of a turbocharger on aviation piston ICE to increase altitude (General Electric).
- ❖ **80 years ago** - the beginning of its mass use in aircraft ICE and the first use in automotive ICE to increase the power density.
- ❖ **55 years ago** - the beginning of its mass use in automotive ICE.
- ❖ **20 years ago** – all car diesel engines and a significant part of gasoline ICEs are equipped with turbochargers.

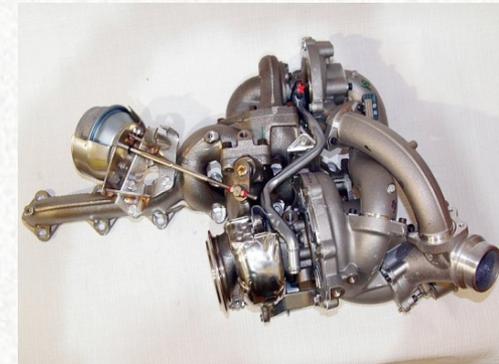


### Advantages of turbocharging :

- simplicity, cheapness,
- reliability, efficiency.

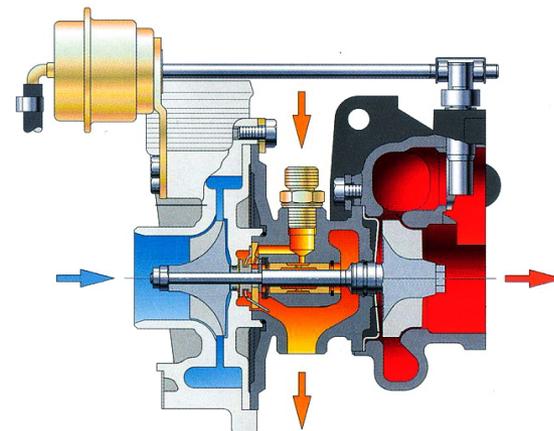
### The main task of turbocharging

- Increase of the air supply to the cylinders in order to increase power density (by 30-50%).



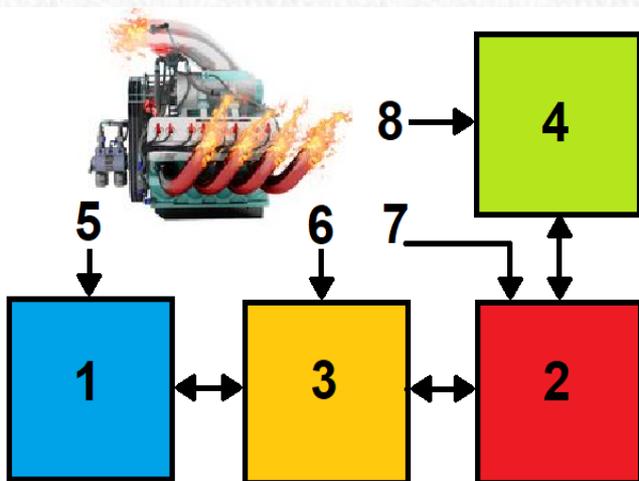
## Characteristic features of turbochargers

- ❑ minimal dimensions to reduce acceleration delay with increasing load (turbo-lag),
- ❑ extremely high rotor speeds (over 200,000 rpm),
- ❑ high sensitivity to damage - very fast development of any damage or failure (100,000 cycles per 30 seconds),
- ❑ significant scale of destruction - a large number of damaged parts (secondary damage),
- ❑ strong impact of the engine on turbocharger faults and vice versa,
- ❑ difficulties in determination of failure causes.



### Block diagram - 4 main units:

- 1) compressor (wheel and housing),
- 2) turbine (wheel and housing),
- 3) center hub rotating assembly (CHRA), incl. bearings and seals (bearings and seals),
- 4) control system, including driver and control unit (Wastegate valve, VNT - variable nozzle turbine or variable compressor).



### External impact on turbocharger (by ICE):

- 5- intake engine system, 6- oil system and engine crankcase,  
7- ICE cylinder and exhaust manifold; 8- ICE control system

# 1. The faults of turbochargers: General description of the problem

## Features of the problem to determine the causes of the failures

1. During the development of ICE, significant efforts were directed to the research and development of new designs of turbochargers.
2. Such constructions were created, however, they are not 100% reliable, because depending on various conditions, faults and failures continue to arise.
3. During this time, no practically useful methods have been created to reliably find the causes of turbochargers failures.
4. In fact, the obligation to determine the causes of turbochargers failures was given by manufacturers to consumers.

### The main difficulty appearing in solving the problem :

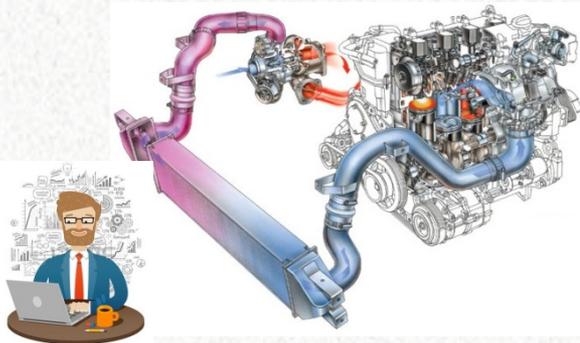
Close interconnection of processes not only inside the turbocharger itself and between its parts, but also of the turbocharger with the engine.

### The consequence of the main difficulty :

It is necessary to investigate all cause-effect relationships, clearly separating the cause of the faults from its consequence (incl. secondary damage to parts).

### The main questions are :

1. Why do you need to know the faults?
2. Where do they come from?
3. What are their causes?



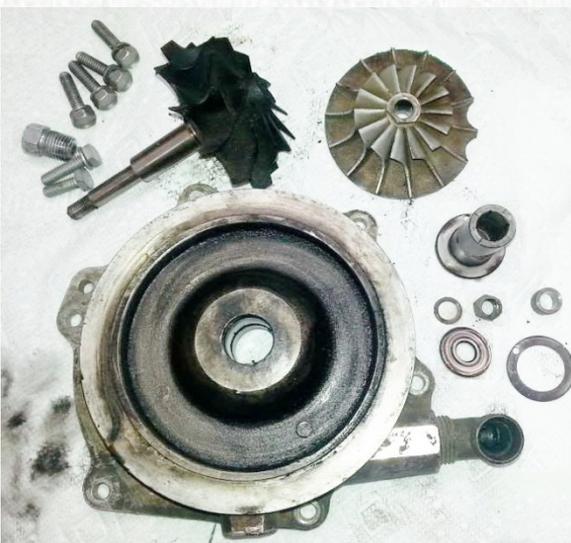
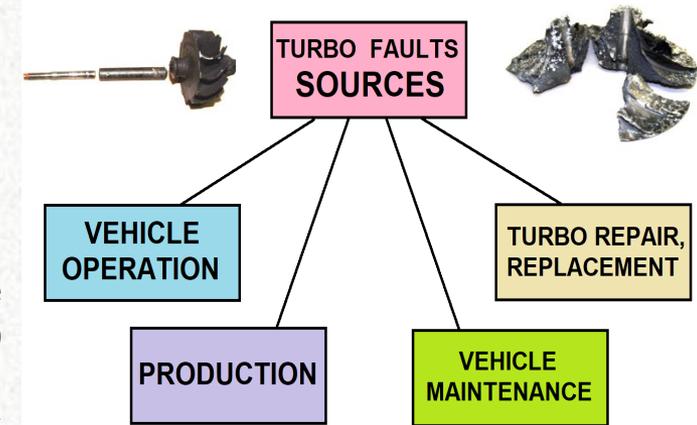
### 1. Manufacture defects (usually more associated with the defects in secondary production)

#### a) primary production

- ❑ - quality of materials, machining and assembly, including rotor balancing and electronic control system adjusting

#### a) secondary production:

- ❖ - recovery (the same as for the primary)
- ❖ - installation (the cause of the failure has not been eliminated - dirt in the oil, in the ducts, intercooler, high pressure in the crankcase, damage to the oil lines, use of sealants, etc.)
- ❖ - ICE service (poor-quality oil, untimely maintenance, abandoned tools and thread components inside engine, etc.)



### 2. Operational faults (often associated with engine)

- ❑ - oil supply failure (low pressure)
- ❑ - oil drain failure (high pressure in the engine crankcase)
- ❑ - dirty oil
- ❑ - inappropriate oil (especially at very low and very high temperatures)
- ❑ - poor air filtration
- ❑ - inlet duct damage (depressurization)
- ❑ - engine components destruction
- ❑ - operational wear
- ❑ - jamming in the driving mechanism (Wastegate, variable nozzles turbine, compressor geometry , etc.)
- ❑ - failure in the turbocharger or ICE control system (control units, connectors, cables)



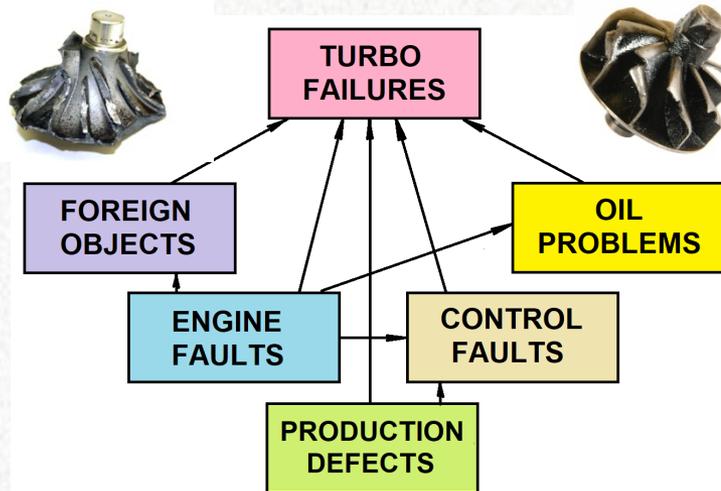
#### The main causes of the turbocharger faults (types of impacts)

1. Operation at specifications faults.
2. Untimely engine maintenance.
3. Service mistakes.
4. Poor repair (mistakes at recovery or replacing).
5. Manufacturing defects.
6. Operational wear.



#### The failure events (the causes of damage, if turbocharger is considered separately)

1. Foreign objects damage (FOD) in compressor or turbine
2. Insufficient oil supply
3. Oil contamination
4. Jamming of the driving mechanism of the control system
5. Control system failure (electrics and electronics)
6. Overspeeding (excess rotor speed)
7. Overheating of turbine, housing



#### Symptoms

1. **Visible to driver:** loss of engine power, noise, smoke, oil consumption, spontaneous engine speed gain, malfunction indicator lamp (MIL).
2. **Visible to mechanic when servicing the vehicle:** trouble codes, external damage, fluids leakage, sometimes – in intake, exhaust systems and engine cylinders.
3. **Visible to specialist-expert on a partially and completely disassembled turbocharger and engine:** various damage and traces on the details - compressor, turbine, housings, bearing assembly, control system, as well as intake, exhaust systems and engine cylinders.

The main task is to connect the symptoms, events and causes into one system

### 1. Compressor

- 1) oil in compressor
- 2) blades wear, erosion
- 3) the blades touching the housing (large radial and / or axial play of the rotor)
- 4) blades damage (deformation)
- 5) blade destruction
- 6) rotor nut - loosening or turning out
- 7) wheel destruction





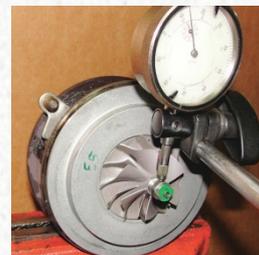
## 2. Turbine

- 1) oil (carbon deposits) in the turbine
- 2) blades touching the housing (large radial and/or axial play of the rotor)
- 3) blades and/or housing mechanical damage (deformation)
- 4) blades and/or housing overheating
- 5) blade destruction
- 6) shaft destruction (separation from the turbine wheel)

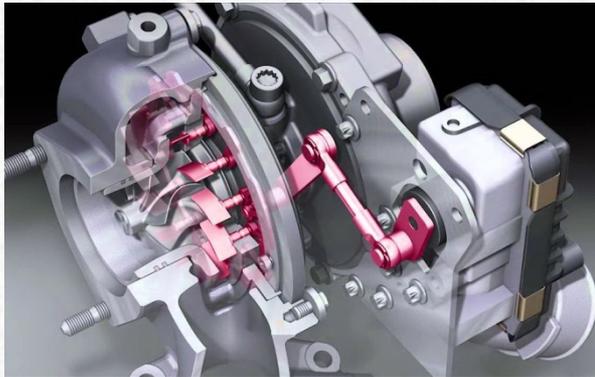
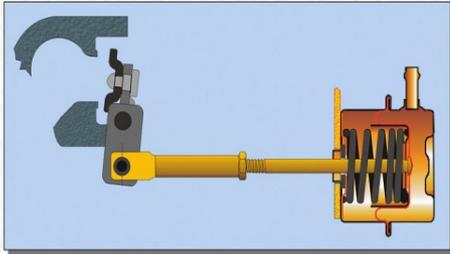


### 3. Bearing assembly:

- 1) oil and/or coolant leaking in connections
- 2) hoses damage
- 3) wear in bearing bushings and shaft journals
- 4) seal rings - wear and leaking
- 5) dirt and deposits in chambers and holes
- 6) bearings, shaft journals - wear and scuffing,
- 7) bearings, shaft journals - overheating and melting
- 8) thrust bearing - wear and scuffing
- 9) thrust bearing - overheating and melting
- 10) bearing housing - overheating
- 11) shaft deformation
- 12) shaft destruction



## 4. The symptoms of turbocharger faults (4/4)



### 4. Control system

- 1) Wastegate valve damage, jamming
- 2) Wastegate actuator diaphragm damage
- 3) vacuum tubes damage
- 4) Wastegate actuator mechanism damage
- 5) variable nozzle turbine (VNT) vanes - damage, overheating
- 6) variable nozzle vanes mechanism - jamming
- 7) control unit failure (electrics and/or electronics)





### Logical-probabilistic method - construction and analysis of the fault tree

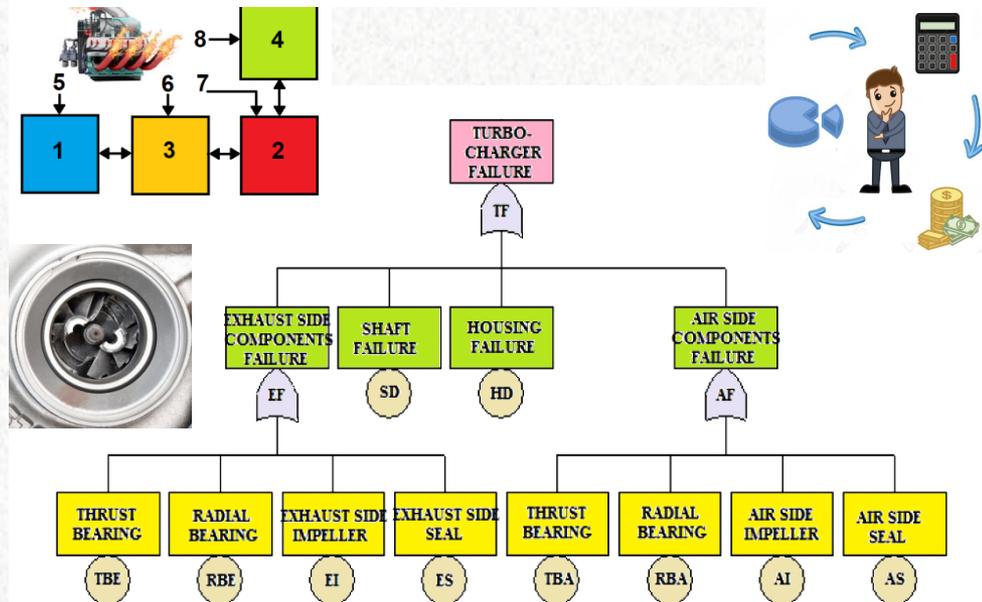
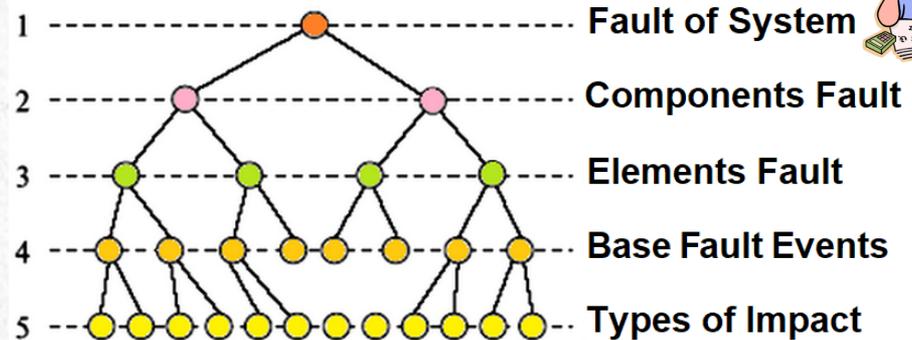
The **fault tree** is a multi-level graphological structure (graph) of causal relationships in the system obtained as a result of tracing dangerous situations in order to find possible causes of their occurrence.

#### Failure tree compilation :

- 1) final (emergency) state of the system,
- 2) subsystems (components, elements) and related events that can lead to system failure,
- 3) the effects that trigger these events.

**The fault tree use** - to analyze the reliability of the system:

1. **Qualitative (logical) analysis** - search all possible combinations of basic or elementary events that can lead to the investigated event (failure) occurrence.
2. **Quantitative analysis** - calculation of the probability of the final event (failure) based on the data on the occurrence probabilities of the basic events (used only in design)

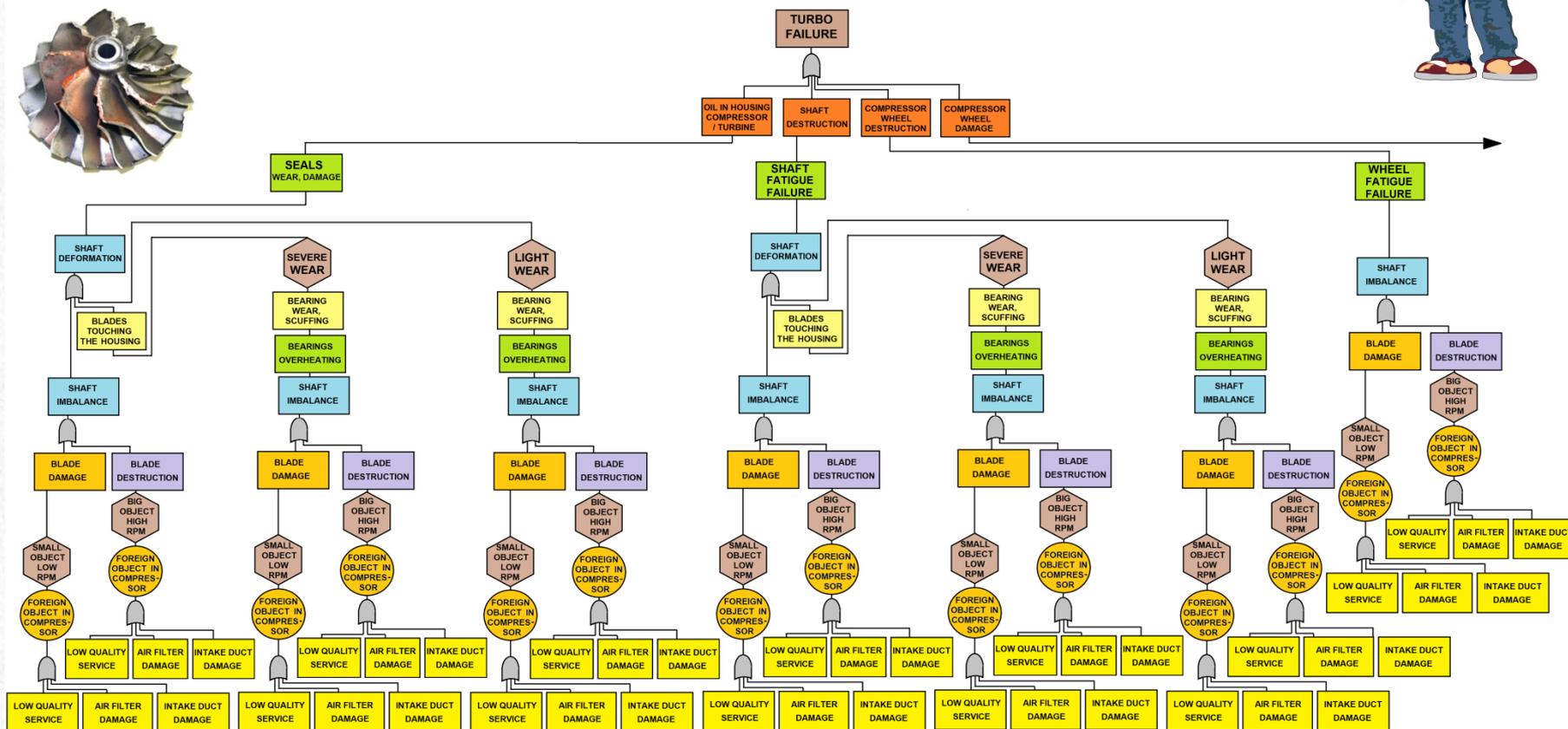


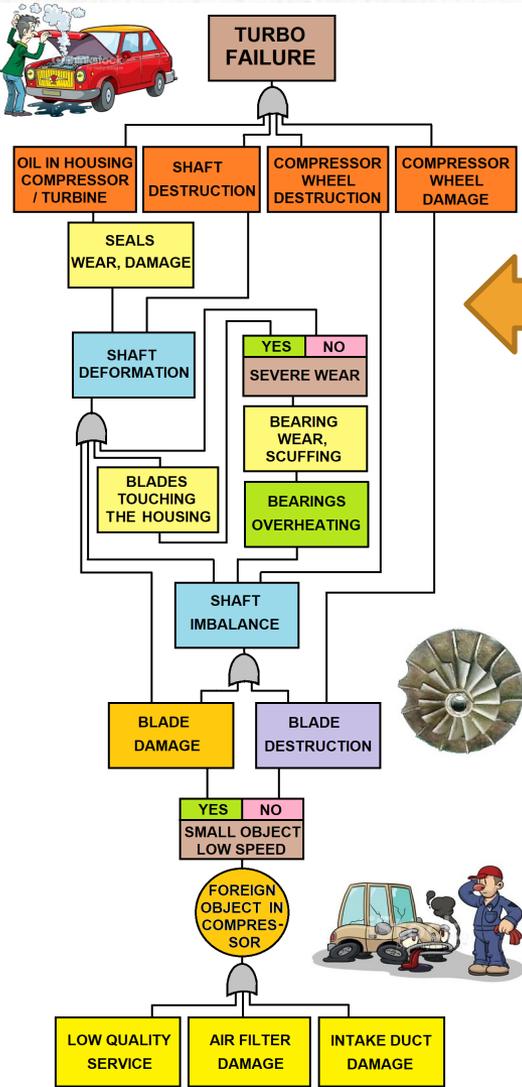
The fault tree of analyzed engine's turbocharger



## Foreign object getting in compressor: Standard fault tree

1. Each event and / or failure has a logical connection with only one subsequent event
2. Excessively bulky construction
3. Suitable for calculating reliability estimates, but poorly suited for logical analysis to determine the cause of a malfunction



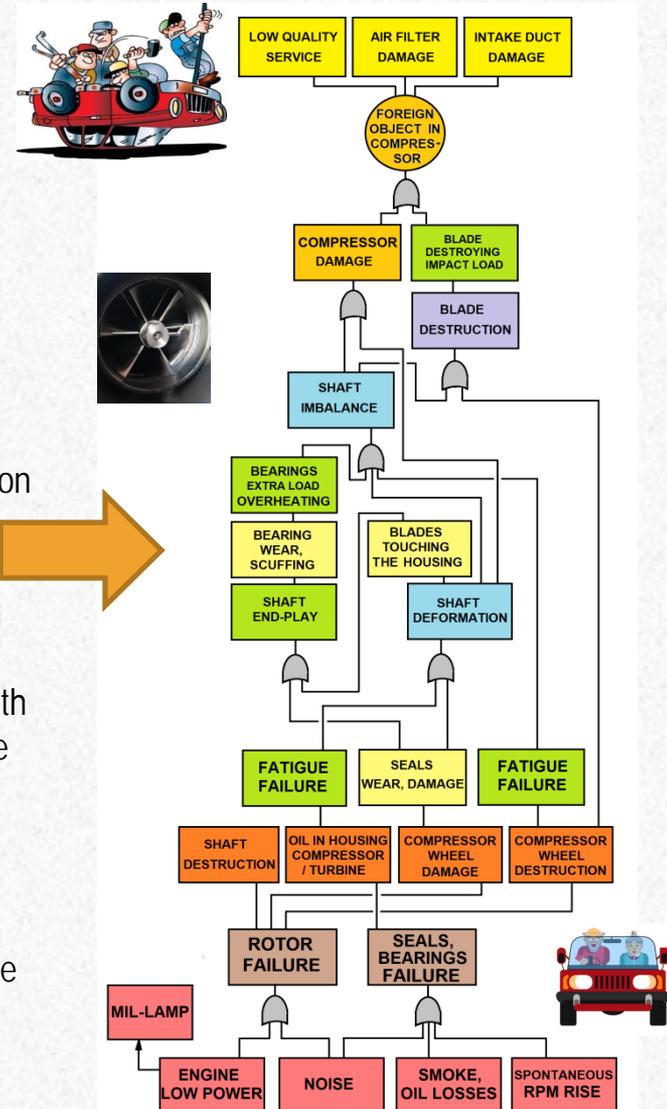


## Modified Fault Tree

- ❖ Each current event can have a logical connection with several subsequent processes (events) at once.
- ❖ Not entirely consistent with the task of determination the fault cause in the direction of analysis.

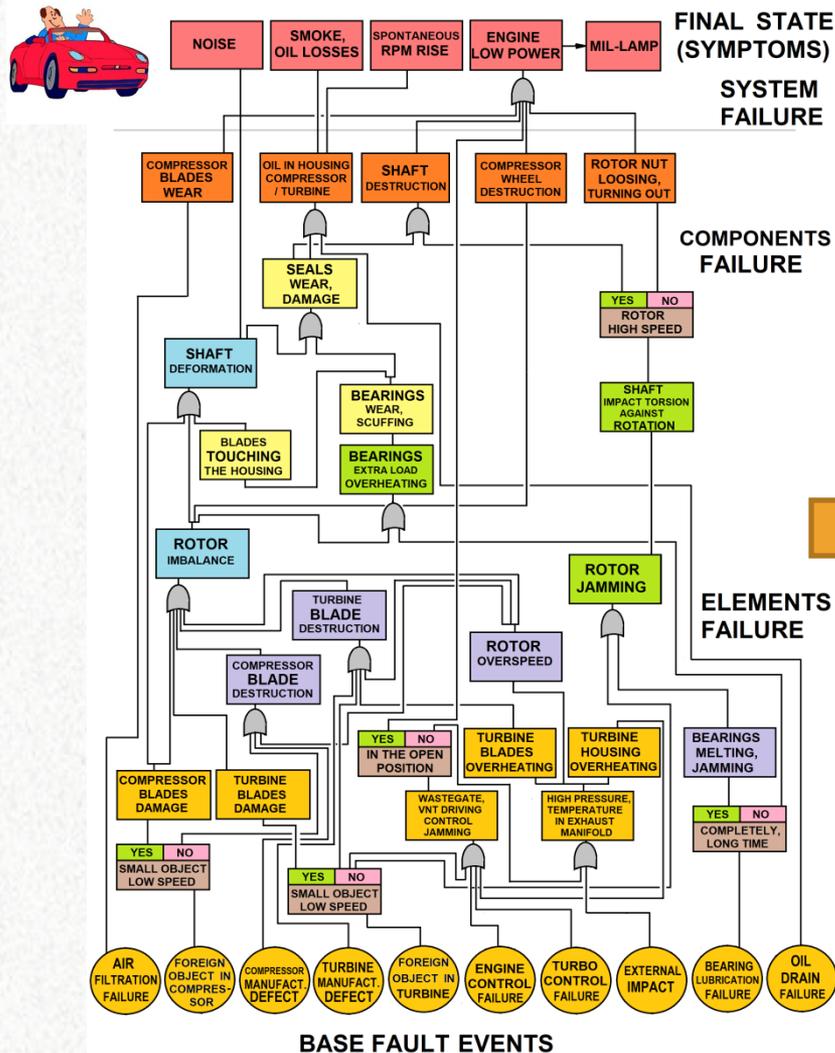
## Reversed fault tree

- ❑ Each event can have a logical connection to several previous and several subsequent events.
- ❑ Logically, the analysis does not go from basic events to failure, but rather from failure to basic events in accordance with the direction of the search for the failure cause.
- ❑ Failure can be divided by signs of its occurrence, visible in the vehicle operation.
- ❑ A process that triggers the failure can be added to each event, which facilitates logical analysis.

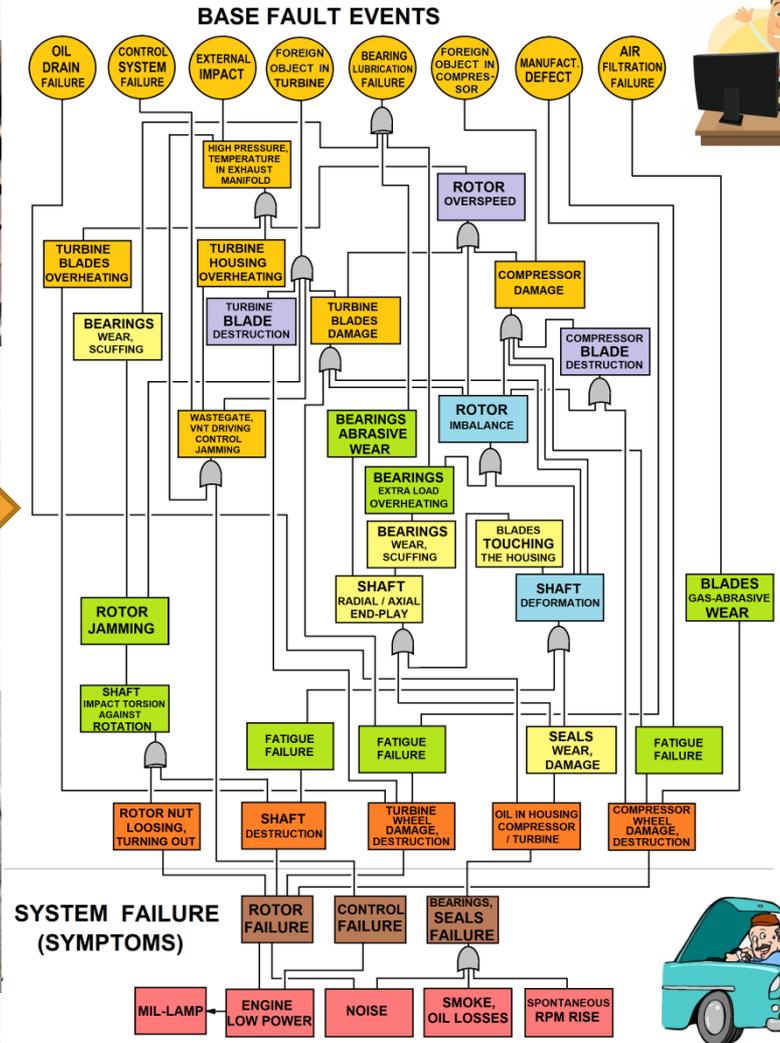


# 6. Method for determination of the failure causes of turbochargers (2/4)

Modified general turbocharger fault tree



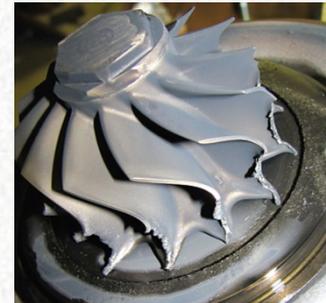
Structural-logical diagram of the turbocharger failures (reversed fault tree)



## Basic events causing failures and types of impacts as the causes of failures

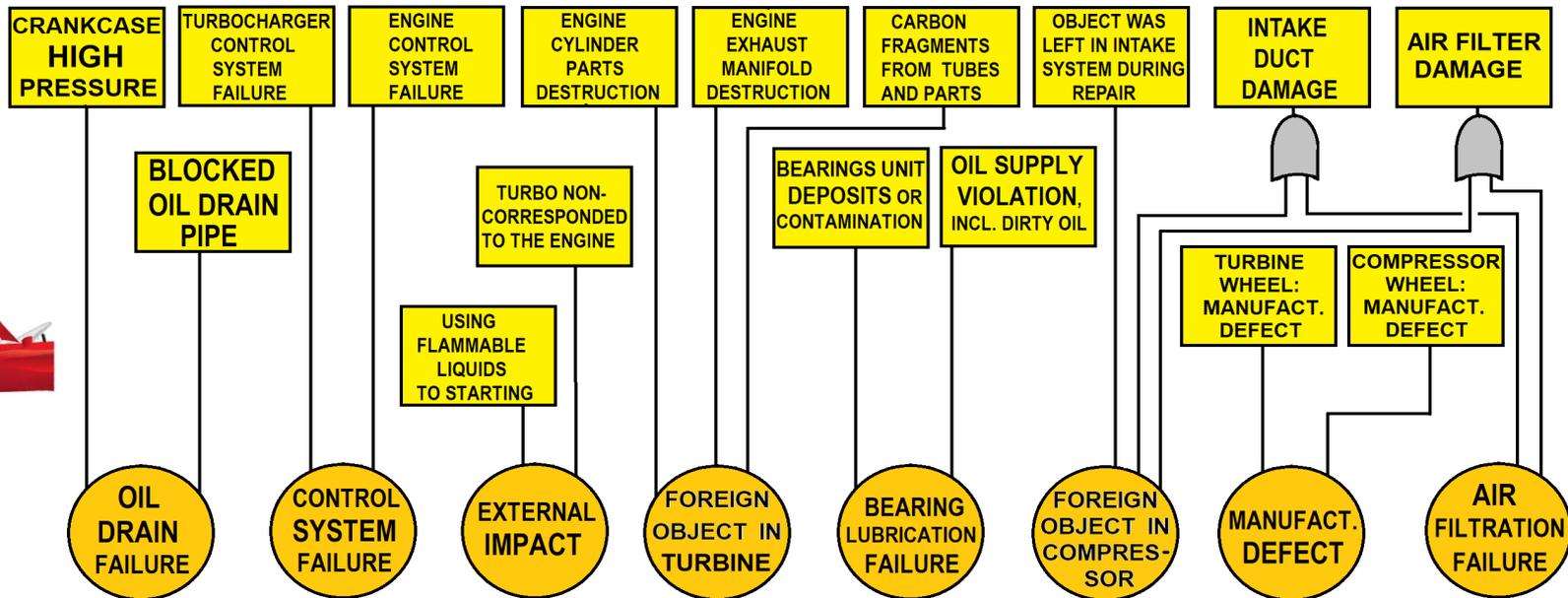


- ❑ compiling a list of basic events (failure events)
- ❑ compiling a list of impacts on the turbocharger (causes of failure)
- ❑ correlation between basic events and impacts



Item No	Item Description	Item Status	Item Category	Item Priority	Item Action	Item Date	Item User
1	Check oil level	OK	Oil	Low	Top up	2023-10-27	John Doe
2	Check oil pressure	OK	Oil	Normal	None	2023-10-27	John Doe
3	Check oil filter	OK	Oil	Normal	None	2023-10-27	John Doe
4	Check oil drain pipe	OK	Oil	Normal	None	2023-10-27	John Doe
5	Check oil pump	OK	Oil	Normal	None	2023-10-27	John Doe
6	Check oil filter	OK	Oil	Normal	None	2023-10-27	John Doe
7	Check oil filter	OK	Oil	Normal	None	2023-10-27	John Doe
8	Check oil filter	OK	Oil	Normal	None	2023-10-27	John Doe
9	Check oil filter	OK	Oil	Normal	None	2023-10-27	John Doe
10	Check oil filter	OK	Oil	Normal	None	2023-10-27	John Doe

## TYPES OF IMPACT



## BASE FAULT EVENTS

## Verification of the reversed fault tree on a specific failure case

Cummins / Holset turbocharger of Cummins ISF3.8 turbodiesel, failure after recondition and short operation.

### Visual inspection:

- the turbine housing has traces of overheating (discoloration) and corrosion,
- destruction in the compressor.

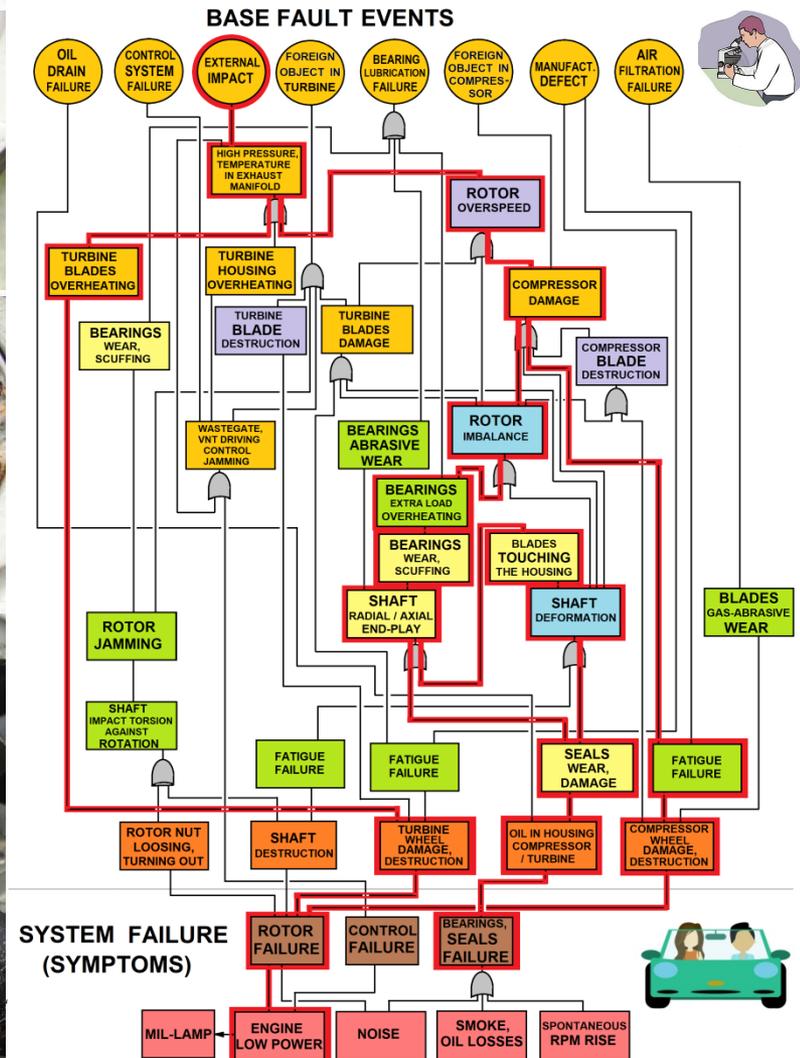
### Disassembling turbocharger housings:

- engine oil in turbine and compressor housings;
- the compressor wheel is destroyed along the hub into two parts;
- the internal surfaces of the compressor housing are damaged and deformed;
- the turbine blades have signs of overheating and are damaged due to contact with the turbine housing in axial and radial directions.

### Disassembling the bearing unit:

- particles of the material of the bearings were detected on the rotor shaft journals;
- the working surfaces of the bearings have traces of semi-dry friction and wear;
- the o-seal of the bearing housing on the side of the turbine wheel is damaged.

**Conclusion** - the failure cause is rotor overspeeding that occurred from the installation of a smaller-sized turbocharger that was unfit for the engine.





1. **Despite great success in the development of highly efficient turbochargers for the ICE, the existing methods for determination of failure causes are too complicated and/or not effective for practical use.**
2. **On the other hand, the well-known method of fault tree analysis (FTA) does not quite fit the tasks for studying the causes of turbocharger faults.**
3. **The performed research demonstrates that the faults of the ICE turbochargers can be analyzed with the means of the modified, or reversed, fault tree.**
4. **The verification conducted on real failure events has demonstrated that the proposed method can be applied with the accuracy sufficient for practice as well as with minimal time consumption.**

# Thanks for attention!

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