Creation of Requirements and Set of Mission Specifications, Design and Operational Effectiveness of Aviation Systems: Main Tasks, Approaches, Education

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Modelling during aircraft life-cycle

AS Life-Cycle Stages

Research → Development → Series Manufacturing → Operation → Write-off and Utilization

- Research in the Field of Critical Technologies, which Provide the Creation of a Prospective AS
- Creation of scientific and technical reserve
- The Research Work Aimed at the Substantiation of Requirements to the Prospective AS in View of all its Life-Cycle Stages

- Testing of New Technologies
- The Creation and Testing of Single Elements and Subsystems
- Prototype and Pre-Production Model Manufacturing
- Tests and More Precise Aircraft Performance Characteristics Definition

- Preproduction
- Testing and Manufacturing of the Development Batch
- Series manufacturing
- Service Tests, Operation Manual

- Operation
- Maintenance process modelling with the purpose of resource saving
- Modernization
- Scheduled Repairs

- Operation
- Utilization process modelling with the purpose of resource saving

Integrated Environment of AS Modelling and Effectiveness Evaluation

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The Relationship of Design Freedom, Knowledge & Cost Committed

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Definition of Complex Aviation System

Complex Aviation System (CAS) consists of:
• vehicle
  – airframe,
  – propulsion system,
  – main aircraft subsystems;
• onboard subsystems for specific mission task

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The significance of effectiveness theory in the process of complex aircraft systems design

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Design algorithm

1. Creation of designed system concept and parameters
2. Modeling of operation of designed system with selected concept under the specified conditions it is created for
3. Making a conclusion about the expedience of change of the concept and parameters with the purpose of design improvement
4. Implementation of the Accepted Design Variant

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Application of methods and theories in design

Modeling by methods of strength of materials

Cantilever beam

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Application of methods and theories in design

Airfoil of the rotor blade

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Application of methods and theories in design

Main Rotor blade

Modeling by methods of aerodynamics and strength theory

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Application of methods and theories in design

Modeling by methods of flight dynamics, aerodynamics, weight calculation, layout design, theory of powerplant characteristics calculation, economics of manufacturing and operation

Helicopter as a transport vehicle

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Application of methods and theories in design

Modeling by methods of theory of evaluation of combat aviation systems operation effectiveness

Combat Helicopter System

Target

Anti-aircraft Rocket Complex

Combat helicopter system

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Theory of effectiveness evaluation is a complex subject

Operations Research
Artificial Intelligence Theory
Firing Theory
Theory of combat survivability
Object Search Theory
Aircraft Aerodynamics
Object Recognition Theory
Calculation of powerplant characteristics
Flight Dynamics
Theory of air traffic control
Economics of complex aviation systems
Management of complex aviation systems

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### Initial data and results of comparison of two alternative Combat Aviation Systems

<table>
<thead>
<tr>
<th>№</th>
<th>Combat Aviation Systems Alternatives</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main performance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Maximum take-off weight, ( W_{t-o} ), kg</td>
<td>6000</td>
<td>9500</td>
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<tr>
<td>2</td>
<td>Empty Weight, ( W_{empt} ), kg</td>
<td>3300</td>
<td>5165</td>
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<tr>
<td>3</td>
<td>Maximum speed, km/h</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>Maximum rate of climb, m/s</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Maximum load factor</td>
<td>4</td>
<td>3,5</td>
</tr>
<tr>
<td>6</td>
<td>Weight of equipment for combat survivability increase, kg</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>7</td>
<td>Maximum quantity of Anti-Tank Guided Missiles, ( n_{ATGM} )</td>
<td>8</td>
<td>12</td>
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</tbody>
</table>

### Comparison Criteria

<table>
<thead>
<tr>
<th>№</th>
<th>Full Payload-to-Maximum Take-Off Weight ratio, ( k_{fpMTO} )</th>
<th>0,45</th>
<th>0,456</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Mathematical expectation of distribution of the number of targets, which will be hit during one attack (all missiles are fired within one target run), ( n_T )</td>
<td>4,8</td>
<td>7,2</td>
</tr>
<tr>
<td>3</td>
<td>Losses of Combat Aviation Systems due to Anti-Aircraft Defense, ( \Delta N_{aircraft} ) Ratio of hit targets to losses because of Anti-Aircraft Defense (all missiles are fired within one target run), ( n_T_{relative} )</td>
<td>0,4</td>
<td>0,53</td>
</tr>
<tr>
<td>4</td>
<td>The number of target runs (four missiles are fired within each target run) Mathematical expectation of distribution of quantity of targets, which are hit during all target runs ( \Sigma n_T ) Losses of Combat Aviation Systems because of Anti-Aircraft Defense System during all target runs, ( \Sigma \Delta N_{aircraft} ) Ratio of hit targets to losses because of Anti-Aircraft Defense system during all target runs, ( \Sigma n_T_{relative} )</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
The presented above example of evaluation of effectiveness of Combat Aircraft Systems Operation has demonstrated the importance of application of methods and models of the theory of evaluation of aviation system operation effectiveness during design process.

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Scheme of Aircraft Systems Group Attack

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System Concept development in JSF program
Various Coast-Guard Vehicles
## Alternative PSRV types

<table>
<thead>
<tr>
<th>PSRV Type</th>
<th>Seaplane Be-200</th>
<th>Ekranoplane “Orlenok”</th>
<th>Helicopter EH-101</th>
<th>VTOL V-22</th>
<th>Patrol vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take-off weight, kg</td>
<td>36000</td>
<td>125000</td>
<td>14280</td>
<td>21550</td>
<td>150000</td>
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<tr>
<td>Cruise speed, km/h</td>
<td>610</td>
<td>350</td>
<td>250</td>
<td>510</td>
<td>70</td>
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<tr>
<td>Range, km</td>
<td>3200</td>
<td>1100</td>
<td>1500</td>
<td>2500</td>
<td>3200</td>
</tr>
<tr>
<td>The necessity of contact with water (water landing) during the evacuation of the people or setting down of the inspection group.</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>The on-board radar range, km.</td>
<td>100</td>
<td>25</td>
<td>100</td>
<td>100</td>
<td>20</td>
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<tr>
<td>The length of liability zone of one PSRV during the PO accomplishment $L_{liabPSRV}$, km.</td>
<td>500</td>
<td>200</td>
<td>300</td>
<td>400</td>
<td>58</td>
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<tr>
<td>The cost of one PSRV, $ mln</td>
<td>29,4</td>
<td>44,5</td>
<td>5,9</td>
<td>11,5</td>
<td>-</td>
</tr>
</tbody>
</table>

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Patrol operation

The probability that the violator ship would not be arrested $P_{n/a}$ is the criterion of patrol operation:

$$K_2 = P_{n/a} \rightarrow \text{min.}$$

The process of evaluation of the patrol operation effectiveness can be divided into two stages:

1-st stage: Determination of:
- the necessary quantity of patrol and search-rescue vehicle bases (PSRVB) $N_{PSRVB}$,
- the total patrol and search-rescue vehicle quantity $N_{PSRV}$,
- the distribution of search-rescue vehicle bases in the region.

2nd stage: Determination of the values of the effectiveness criterion $K_2$ for all types of vehicles.
Search and rescue operation

The critical values of the weather parameters, which should be taken into account during the calculations, and the appropriate ranges.

1. The lighting conditions: day; night.
2. The amount of cloudiness: clear or cloudy weather.
3. The wind velocity $V_w$: $V_w < 16$ m/s; $V_w > 16$ m/s.
4. The wave height $H_w$: $H_w < 1,25$ m; $1,25$ m $< H_w < 3,5$ m; $H_w > 3,5$ m.
5. The water temperature $t_{\text{water}}$: $t_{\text{water}} < 5^\circ$ C; $5^\circ < t_{\text{water}} < 12^\circ$ C; $t_{\text{water}} > 12^\circ$ C.
6. The air temperature $t_{\text{air}}$: $(t_{\text{air}} < 0^\circ$ C; $t_{\text{air}} > 0^\circ$ C).

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The criterion of a search and rescue operation

The probability of the successful rescue operation over the whole zone and year is the criterion of operational effectiveness during a rescue operation \( K_1 \).

\[
K_1 = \sum_{i=1}^{I} \frac{S_{P_i} \times P_i}{S_0} \rightarrow \text{max}
\]

Where:

- \( S_{P_i} \) is the area where the rescue probability is equal to \( P_i \);
- \( S_0 \) is the area of the whole zone.

The value of the probability of the successful rescue of people \( P_i \) depends on the distance \( r \) from base and is calculated by the formula:

\[
P_i = \sum_{j=1}^{n_w} P_{rj} \times P_{dj} \times P_j;
\]

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Dependence of rescue probability on distance between RO and PSRVB

Figure 7. The rescue probability $P_i$ as a function of the distance $r$ between the RO and PSRVB in the region of Kuril Islands when there is a communication with the RO

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The dependence of probability that violator would not be arrested on cost of creation of CGS

Figure 10. The probability that the violator would not be arrested $K_2$ as a function of the cost of creation of the CGS air component $K_3$ (the region of Kuril Islands)

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Figure 11. The rescue probability $K_1$ and the probability that the violator would not be arrested $K_2$ as functions of cost of creation of the CGS air component $K_3$ (the region of Kuril Islands, the information about RO location is available all the time).
Creation and Optimization of Multi-Type Airliner Fleet

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General Problem Definition and Breakdown

Creation of a rational fleet of passenger airliners

Optimization of air route multitudes for each type 
\( (N_{\text{pass}}^{\max}, L) \) and quantity of types in the fleet \((m)\)

**Criterion:**
Total expenses for fleet operation
\[
F(X, A) = \sum_i FD_i(x, y_i, S_i)
\]

Optimization of airplane parameters and performance
and organization of airplane operation
(required quantity of airplanes of one type)

**Criterion:**
Total expenses on transportation on the multitude of the routes served by the regarded airplane
\[
FD_i = \sum_{x \in D_i} f(x_n, y_i)
\]

Optimization of allocation of airplane types on the regarded routes
(creation of route multitudes \(D_i\))

**Criterion:**
Expenses on one flight
\[
f(x_n, y_i)
\]

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### Initial data

Dependency of passenger flow (mln. pass km) depending on range of air passenger transportation and average quantity of passengers per flight

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<td>500-750</td>
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<td>750-1000</td>
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<td>1000-1250</td>
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</tbody>
</table>

**Average annual passenger flow, mln. pass. km.**

Initial data

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The quantity of aircraft types in the fleet is smaller than the given number TRUE

Variation of quantity of airplane types within the fleet from 60 to 1

Optimization of route multitudes for each airplane type

Optimization of performance and parameters by the following variables

Selection of initial values of design parameters and variables

Aircraft fleet creation algorithm

Initial data - demand

Selection of initial values of design parameters and variables

Optimization of performance and parameters by the following variables

Optimization of route multitudes for each airplane type

TRUE

FALSE

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Analysis of the derived data

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Department of Design and Operational Effectiveness of Complex Aviation Systems of Moscow Aviation Institute (MAI)

The department was founded more than 30 years ago; We teach specialists in the field of Design and Operational Effectiveness of Complex Aviation Systems; The specialists work in:

• aircraft design companies
  - Chief Designer Departments,
  - Departments of Operational Effectiveness,
  - Conceptual Design Departments ;
• Civil and Military Aviation Research Centers;
• Airline Companies.

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The curriculum structure for specialty “Airplane Design” (Engineers (Masters) Degree in MAI) (without liberal arts)

<table>
<thead>
<tr>
<th>System Engineering</th>
<th>Aviation Mechanical</th>
<th>Aircraft Design</th>
<th>Manufacturing, Operation, and Maintenance</th>
<th>Economic and Effectiveness</th>
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<tbody>
<tr>
<td></td>
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<td>Airplane Design</td>
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<td>Theory of Mechanisms</td>
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<td>Descriptive geometry and Technical Drawing</td>
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<td>Structural Materials</td>
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<td>Processing Technique of Structural Materials</td>
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<td>Airplane manufacturing technology</td>
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<td>Mathematics &amp; Computer Sciences</td>
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Groups of Subjects

- System Engineering
- Aviation Mechanical
- Aircraft Design
- Manufacturing, Operation, and Maintenance
- Economic and Effectiveness

- Aircraft Subsystems
- Aircraft Engines
- Thermodynamics and Heat Transmission
- Electrical Engineering and Radio Electronics
- Theoretical Mechanics
- Physics
- Aerodynamics
- Strength of Materials
- Aircraft Structural Mechanics
- Airplane Strength Calculations
- Flight Dynamics

Zhuravlev V.N.
The curriculum structure for specialty “Design and Operational Effectiveness of Complex Aviation Systems” (Engineers (Masters) Degree in MAI) (without liberal arts)

<table>
<thead>
<tr>
<th>Groups of Subjects</th>
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<tbody>
<tr>
<td><strong>Subsystem</strong></td>
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<tr>
<td><strong>Aviation and Mechanical</strong></td>
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<tr>
<td><strong>Mathematics &amp; Computer Sciences</strong></td>
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<tr>
<td><strong>Complex Aviation System Design</strong></td>
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<tr>
<td>** Mathematical Modeling and Operation Research**</td>
</tr>
<tr>
<td><strong>Manufacturing, Operational, Maintenance, and Economic</strong></td>
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</table>

- **Aviation and Mechanical**
  - Aircraft Subsystems
  - Aircraft Engines
  - Electrical engineering and radio electronics
  - Theoretical Mechanics
  - Descriptive geometry and Technical Drawing

- **Complex Aviation System Design**
  - Aircraft Structure Design
  - Airplane Structure
  - Flight dynamics
  - Aerodynamics
  - Machine Elements and Theory of Mechanisms
  - Strength of Materials
  - Certification
  - Aviation System Design
  - Operational Effectiveness of Complex System
  - Complex Aviation System Testing
  - Complex Aviation System Control
  - Applied Systems Theory
  - Artificial Intellect Systems
  - Operational Modeling of Complex Aviation Systems
  - Introduction to Aeronautical Engineering Complex Aviation System Design

- **Mathematical Modeling and Operation Research**
  - Operation research
  - Complex System Modeling Technology
  - Management Theory of Complex System
  - Theory of Complex System Mathematical Modeling

- **Manufacturing, Operational, Maintenance, and Economic**
  - Reliability and survivability
  - Aviation Complex System Economics
  - Management and Marketing
  - Economics
  - Aircraft manufacturing technology
  - Materials science and technology

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