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

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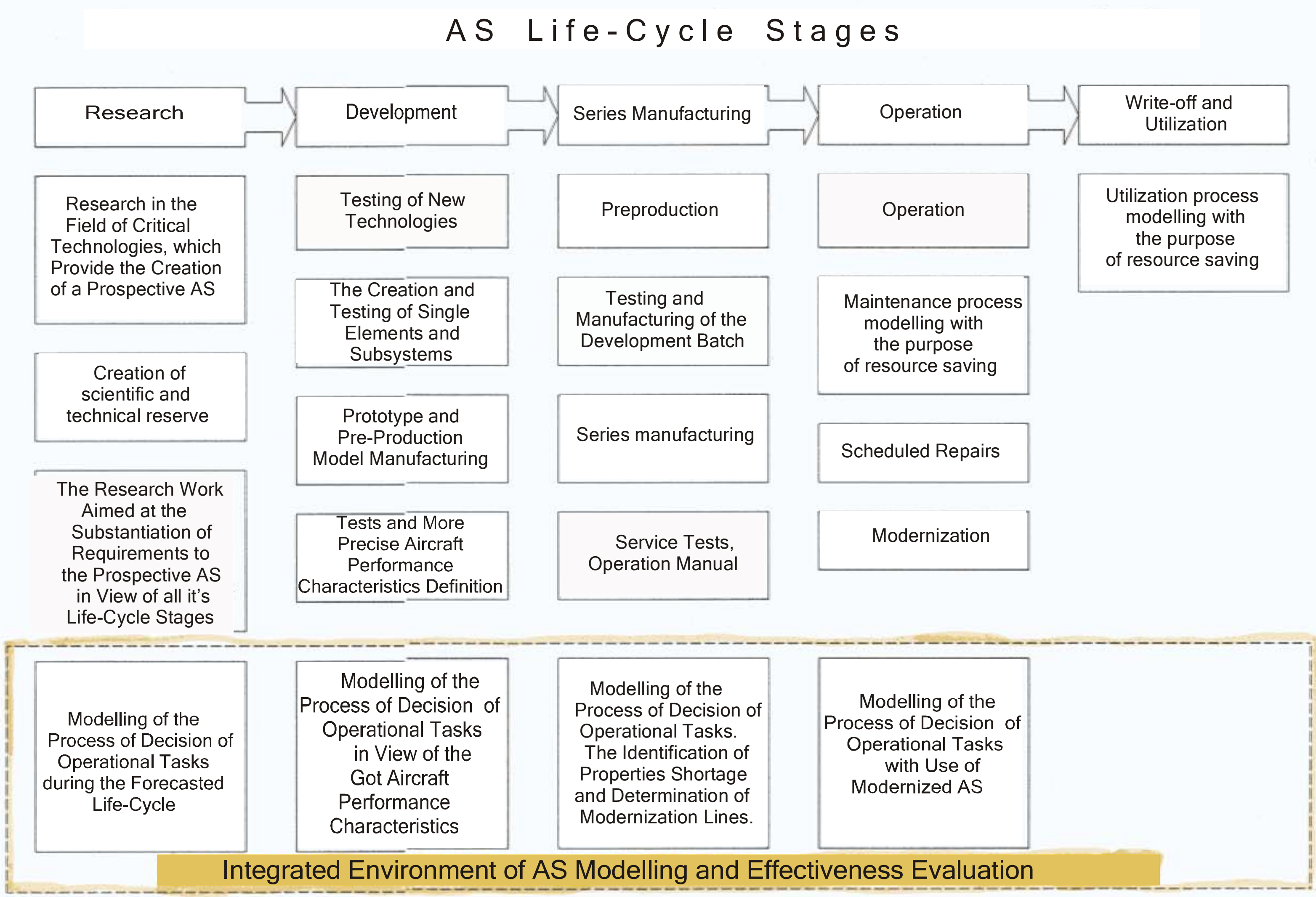
SSAU, Samara, Russia

Modelling during aircraft life-cycle



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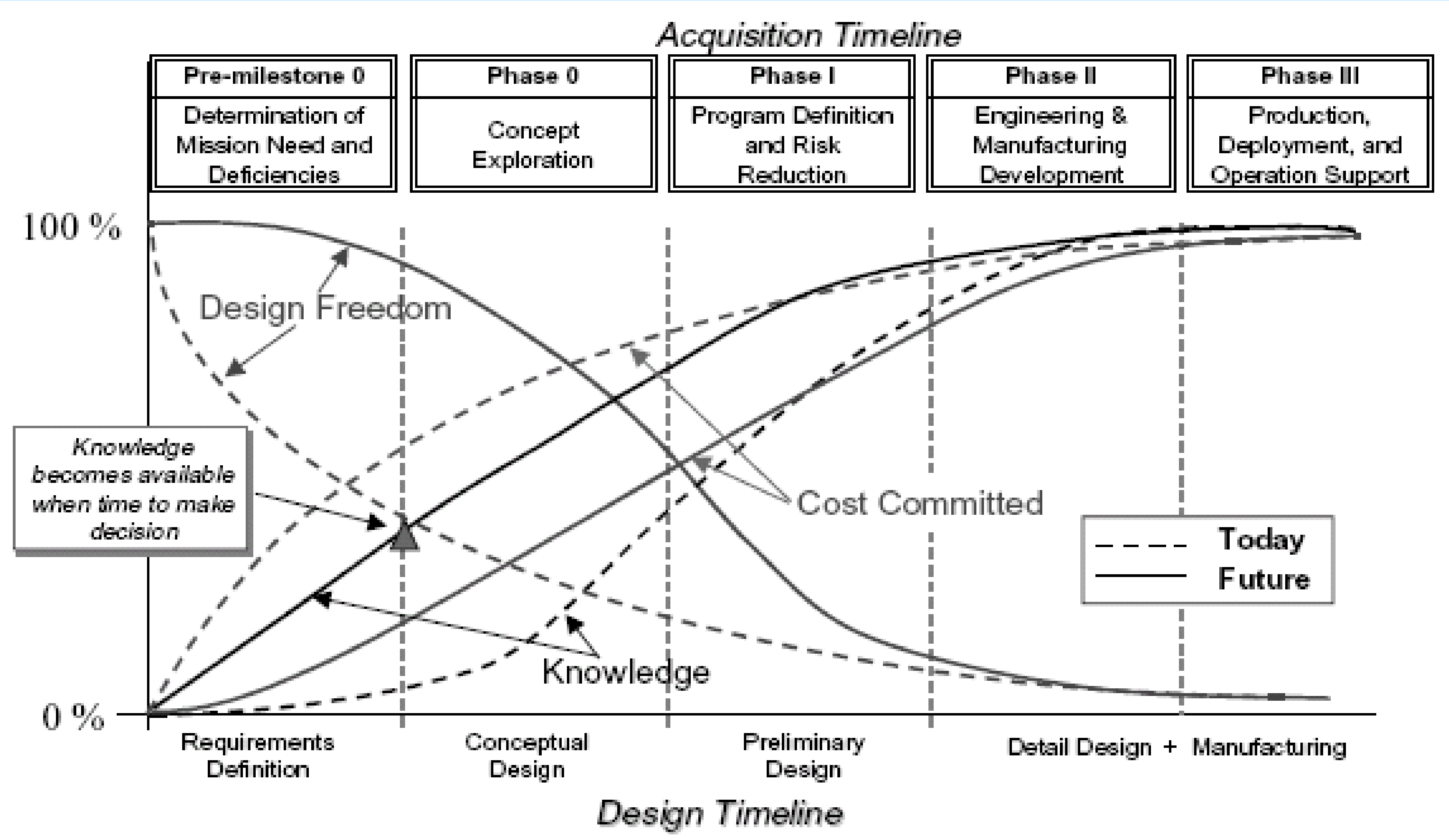
The Relationship of Design Freedom, Knowledge & Cost Committed



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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

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

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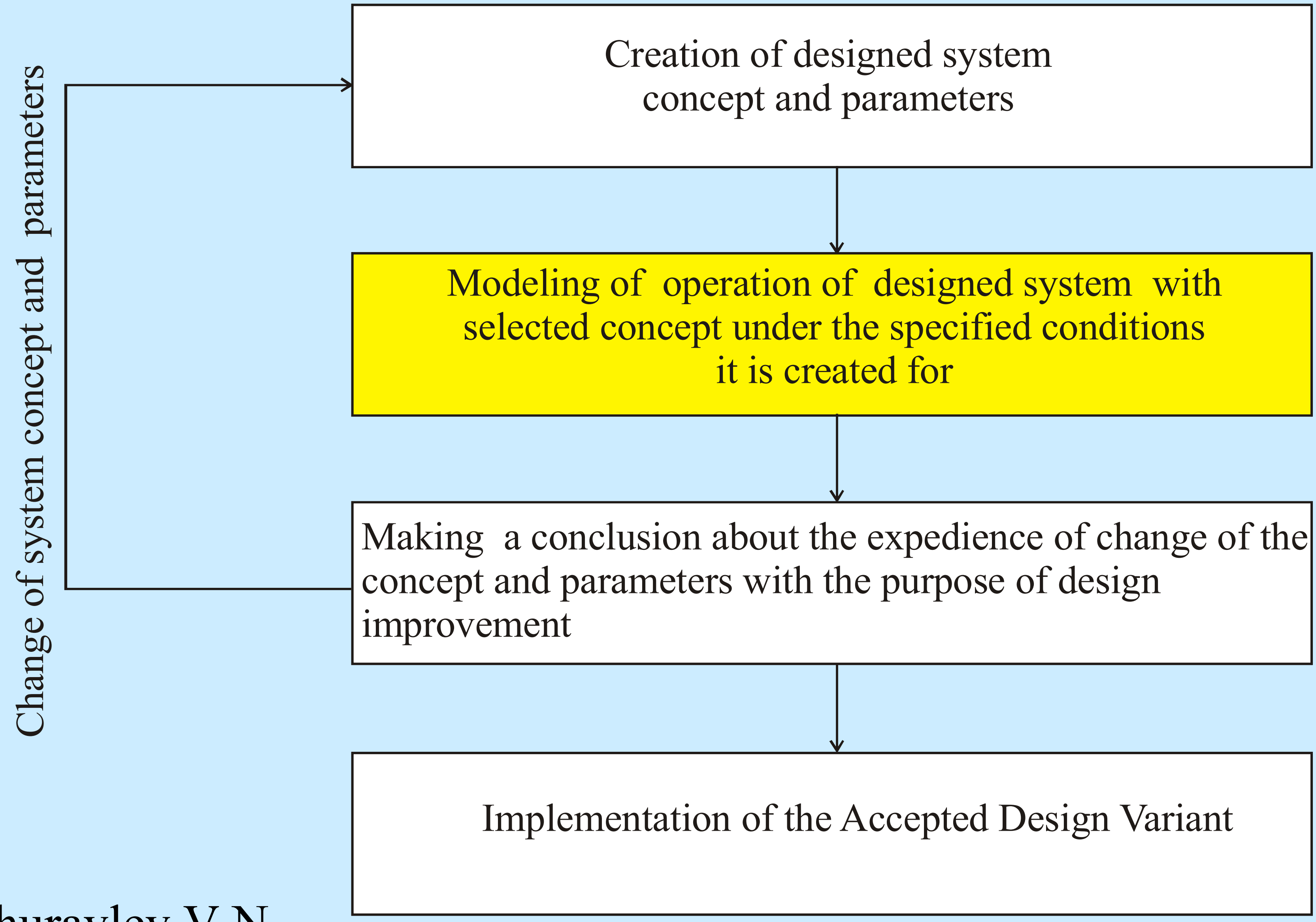
Design algorithm



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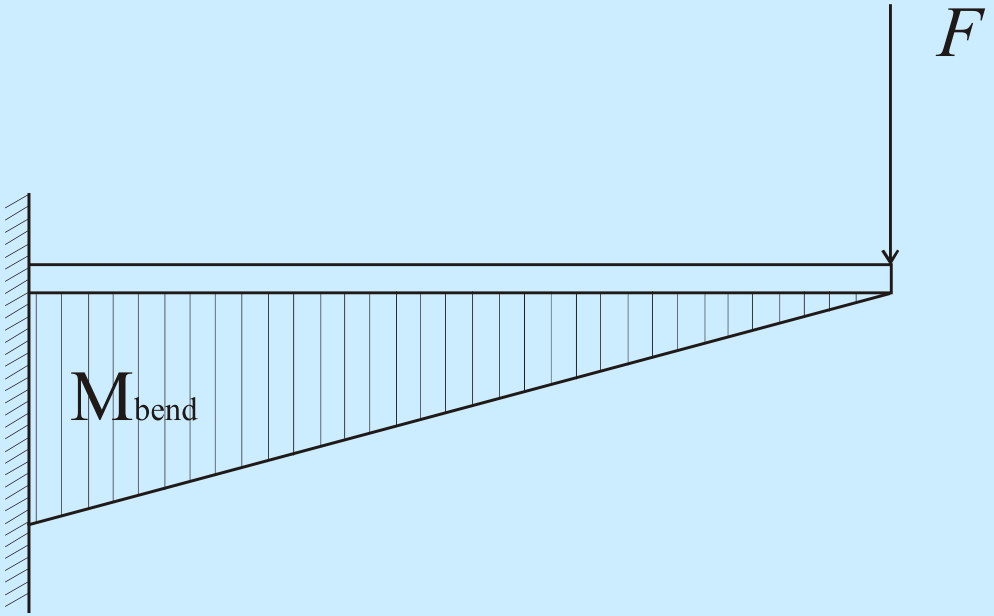
Application of methods and theories in design

Modeling by methods of strength of materials



Cantilever beam

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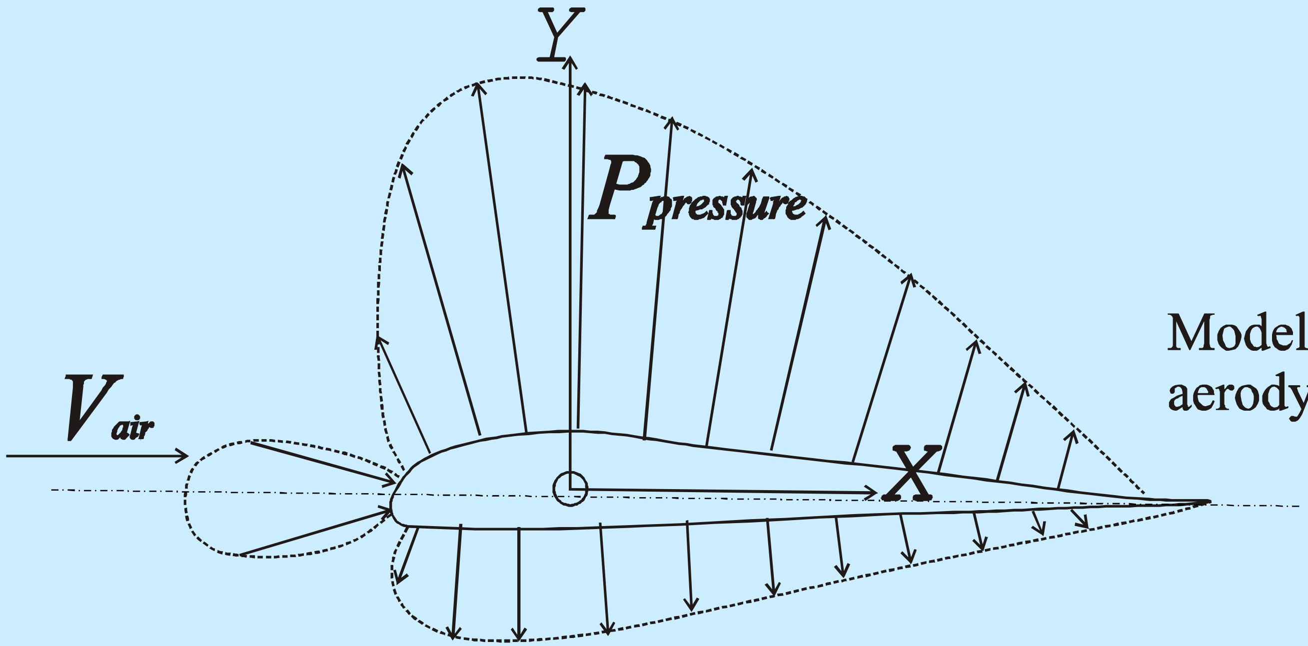
Application of methods and theories in design



Modeling by aerodynamics methods

Airfoil of the rotor blade

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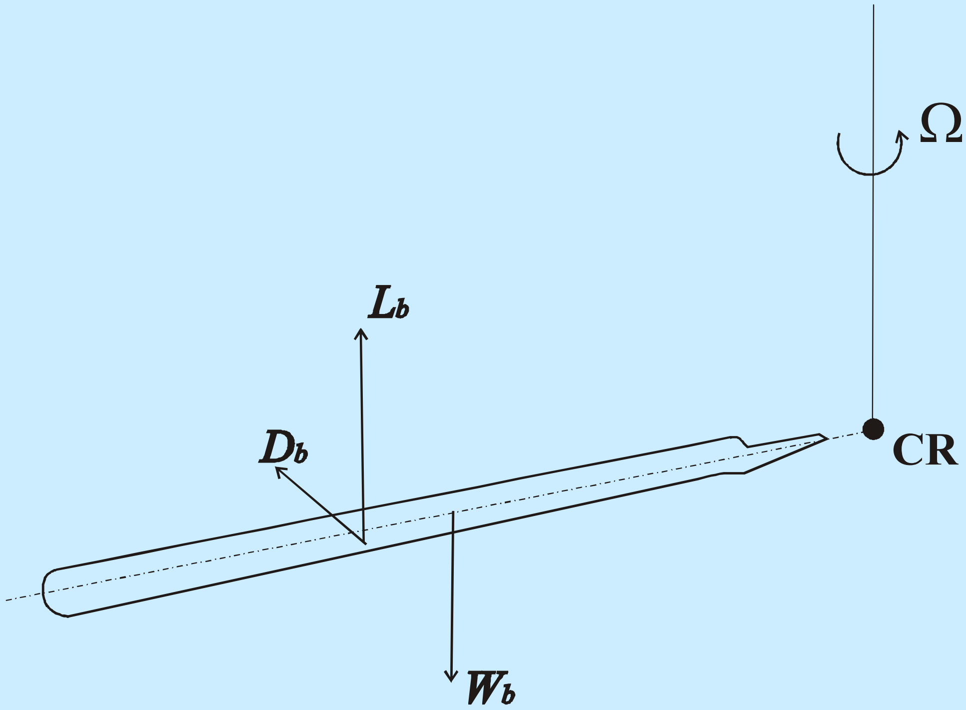
Application of methods and theories in design



Modeling by methods
of aerodynamics and strength theory

Main Rotor blade

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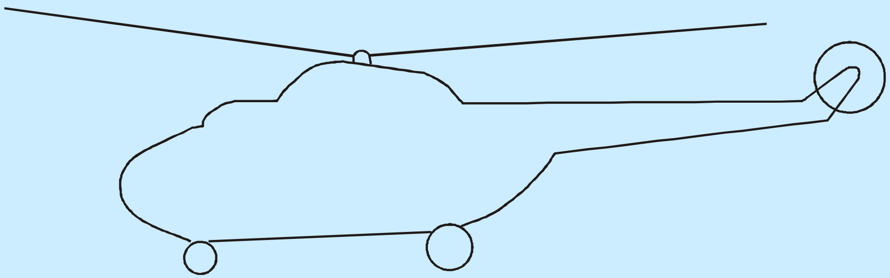

Modeling by methods of flight dynamics, aerodynamics, weight calculation, layout design, theory of powerplant characteristics calculation, economics of manufacturing and operation

Helicopter as a transport vehicle

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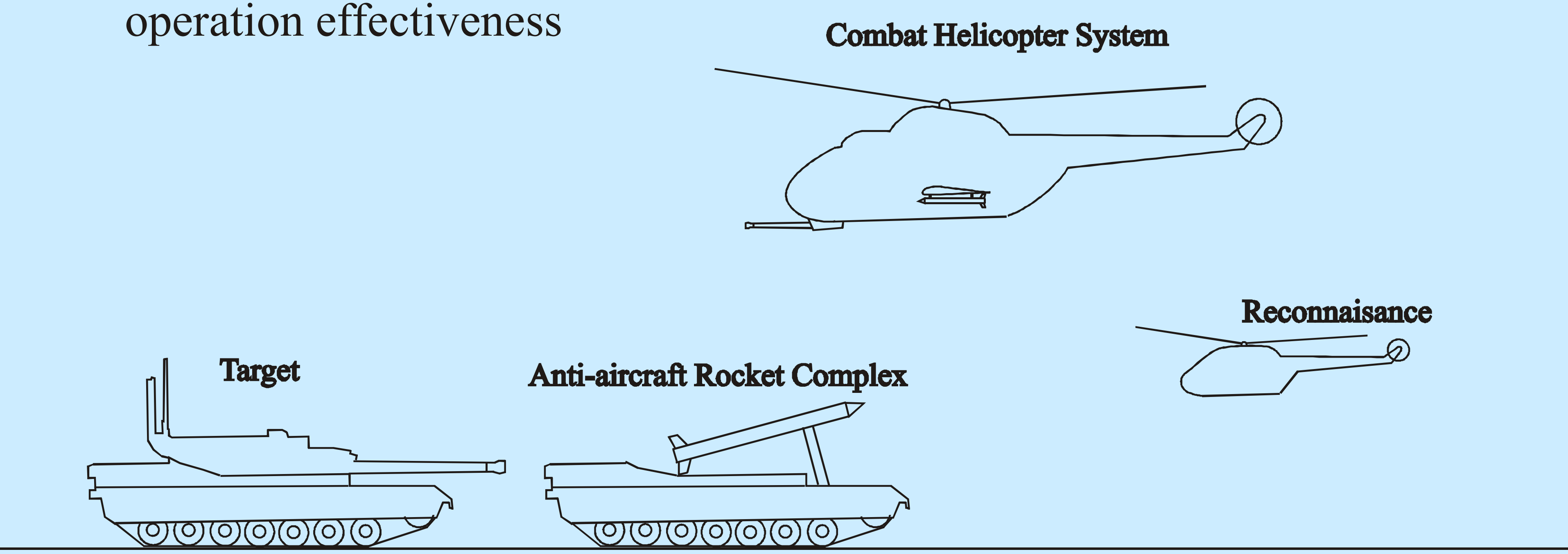
Application of methods and theories in design

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



Combat helicopter system

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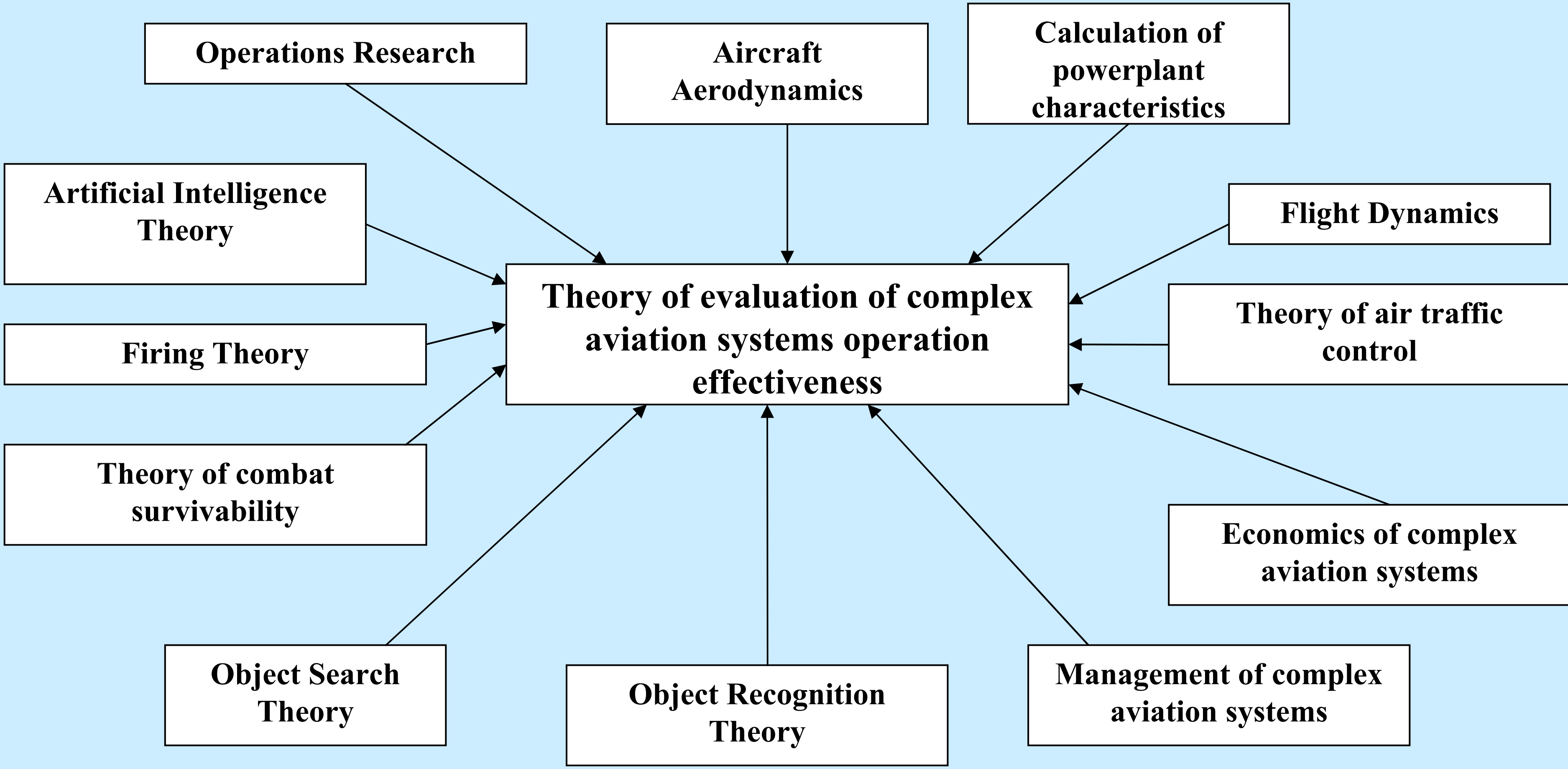
Theory of effectiveness evaluation is a complex subject



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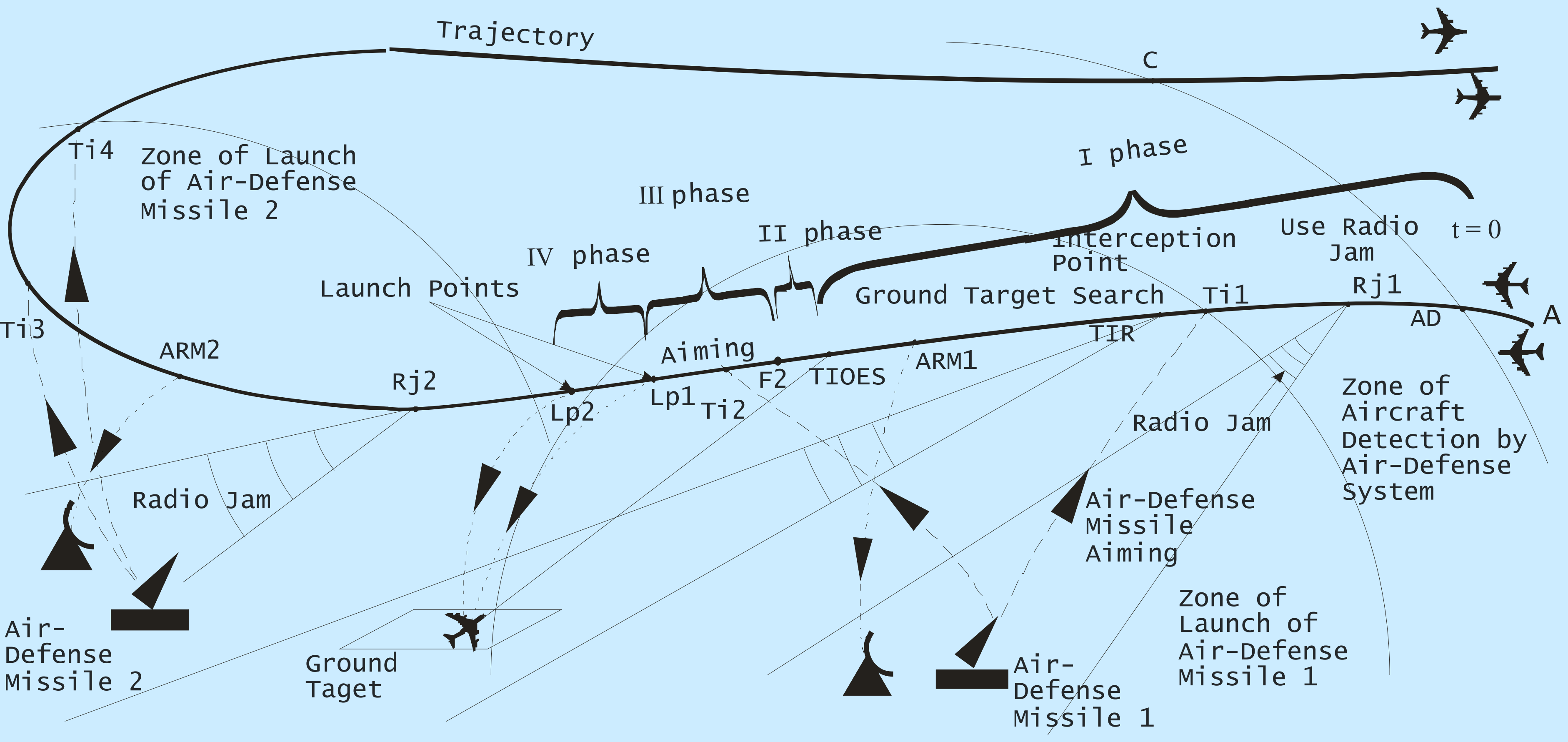
Initial data and results of comparison of two alternative Combat Aviation Systems

№	Combat Aviation Systems Alternatives	1	2
	Main performance		
1	Maximum take-off weight, $W_{t\text{-}o}$, kg	6000	9500
2	Empty Weight, W_{empt}, kg	3300	5165
3	Maximum speed, km/h	300	300
4	Maximum rate of climb, m/s	12	8
5	Maximum load factor	4	3,5
6	Weight of equipment for combat survivability increase, kg	300	200
7	Maximum quantity of Anti-Tank Guided Missiles, n_{ATGM},	8	12
	Comparison Criteria		
1	**Full Payload-to-Maximum Take-Off Weight ratio, k_{fpMTO}**	**0,45**	**0,456**
2	**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	**4,8**	**7,2**
3	**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), $n_{T\_relative}$*	0,4 **12**	0,53 **13,5**
4	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 Σn_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, $\Sigma n_{T\ relative}$***	2 2,5 0,45 **5,6**	3 4,5 0,96 **4,7**

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.

Scheme of Aircraft Systems Group Attack



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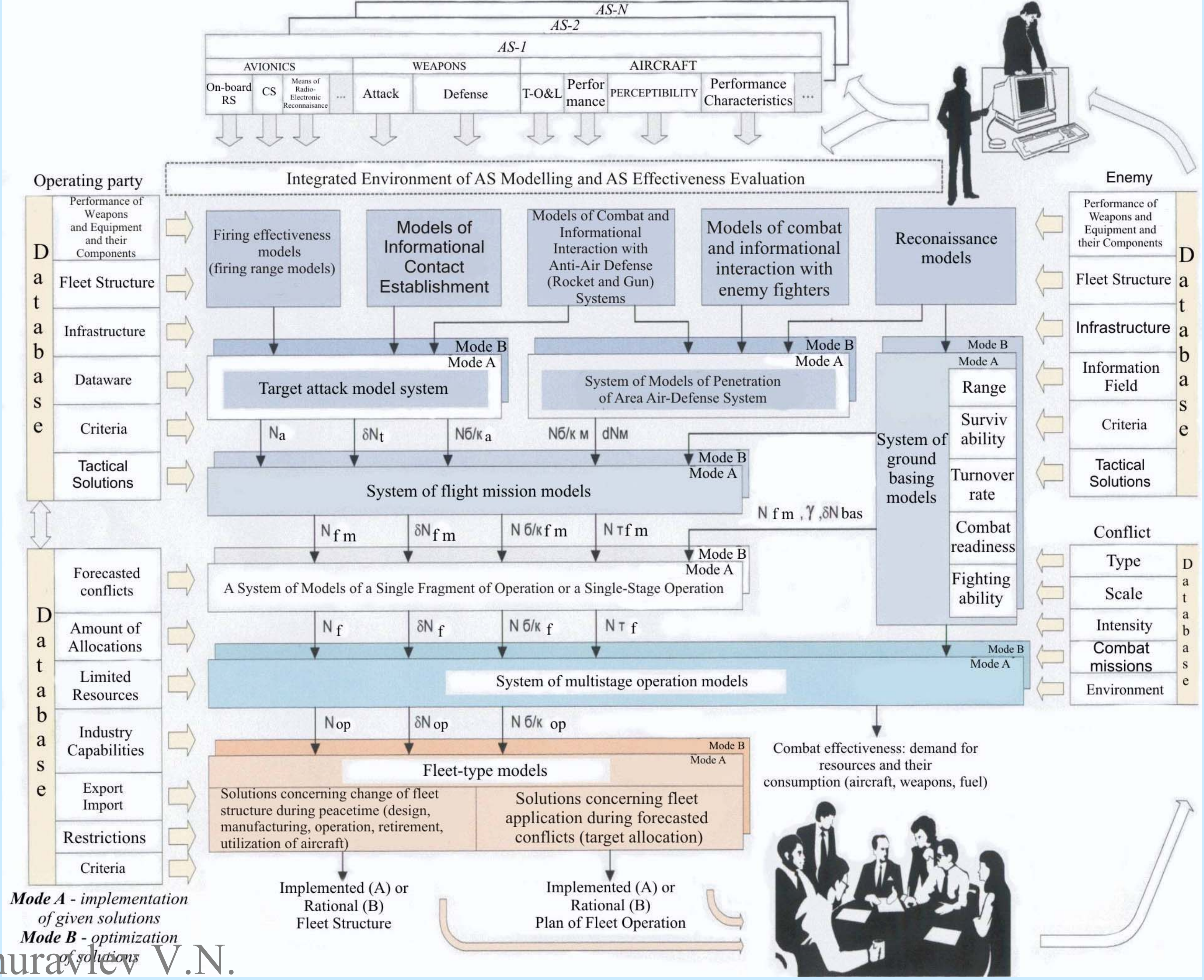

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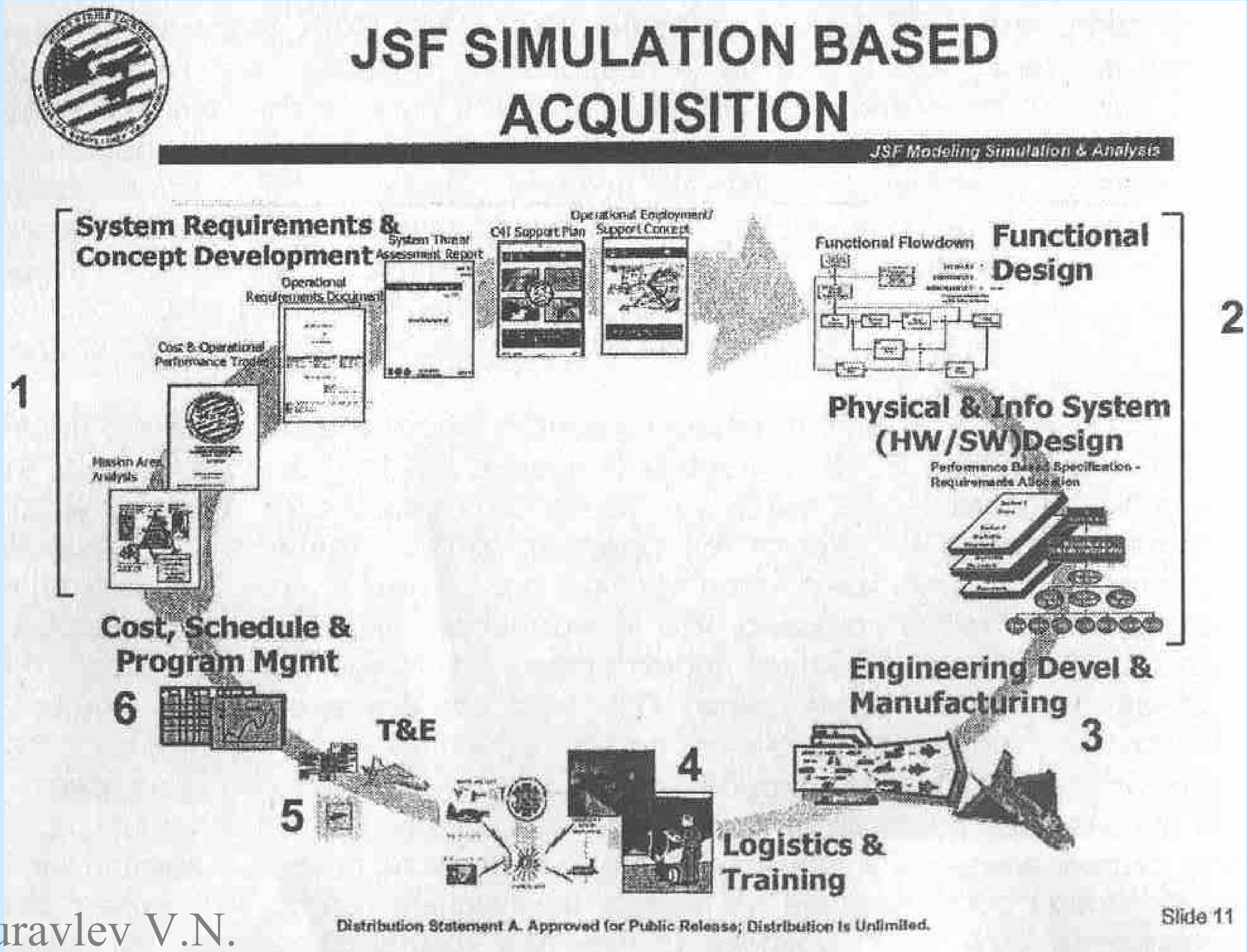
System Concept development in JSF program



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Various Coast-Guard Vehicles

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Alternative PSRV types

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

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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:

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

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.

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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; $1{,}25 \text{ m} < H_w < 3{,}5$ m; $H_w > 3{,}5$ m.
5. **The water temperature t_{water}:** $t_{water} < 5^o$ C; $5^o < t_{water} < 12^o$ C; $t_{water} > 12^o$ C.
6. **The air temperature t_{air}:** ($t_{air} < 0^o$ C; $t_{air} > 0^o$ 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 $\boldsymbol{K_1}$.

$$K_1 = \sum_{i=1}^{I} \frac{S_{Pi} \times P_i}{S_0} \rightarrow \max$$

Where:

$\boldsymbol{S_{pi}}$ is the area where the rescue probability is equal to $\boldsymbol{P_i}$;

$\boldsymbol{S_0}$ is the area of the whole zone.

The value of ***the probability of the successful rescue of people*** $\boldsymbol{P_i}$ depends on the distance ***r*** from base and is calculated by the formula:

$$P_i = \sum_{j=1}^{j=n_W} P_{rj} \times P_{dj} \times P_j;$$

VTOL: The rescue probability P_i as a function of the distance r

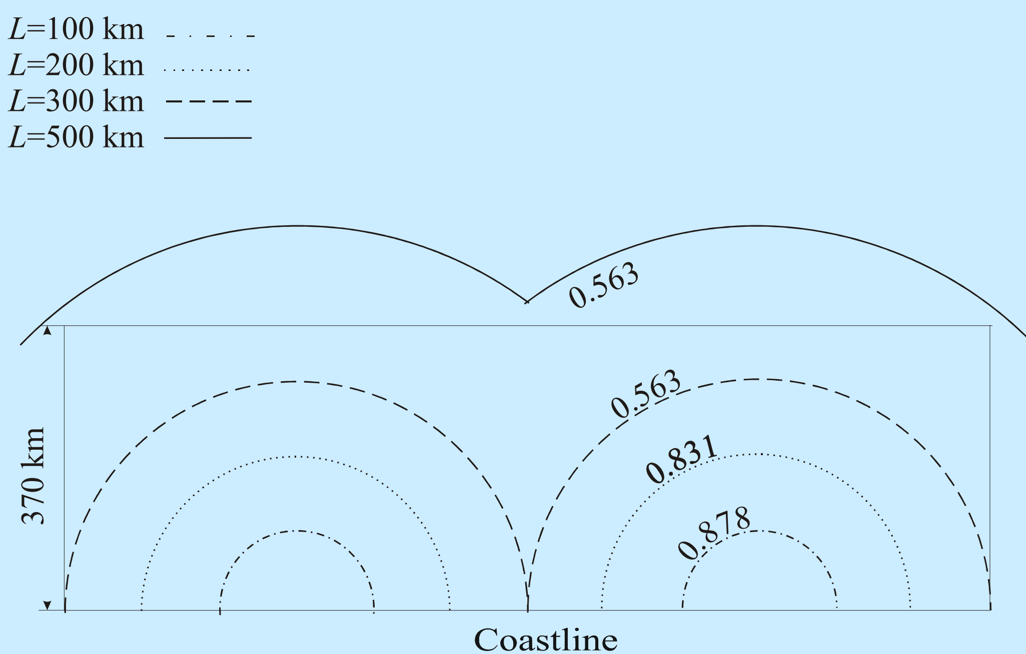

Figure 6.

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Dependence of rescue probability on distance between RO and PSRVB

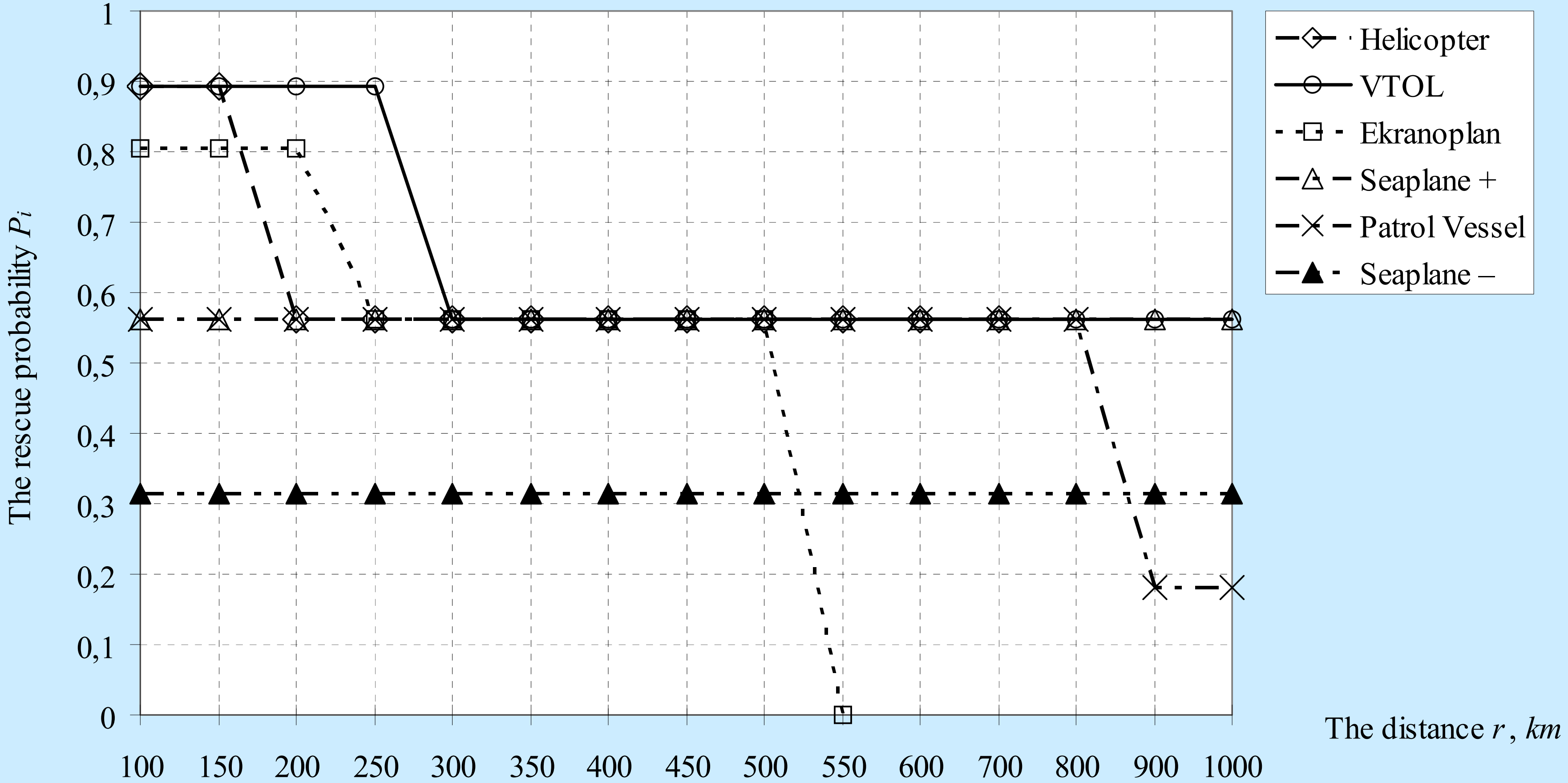

Figure 7. The rescue probability P_i as a function of the distance r between the RO and PSRVB in the region of Kuril Islands when there is a communication with the RO

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

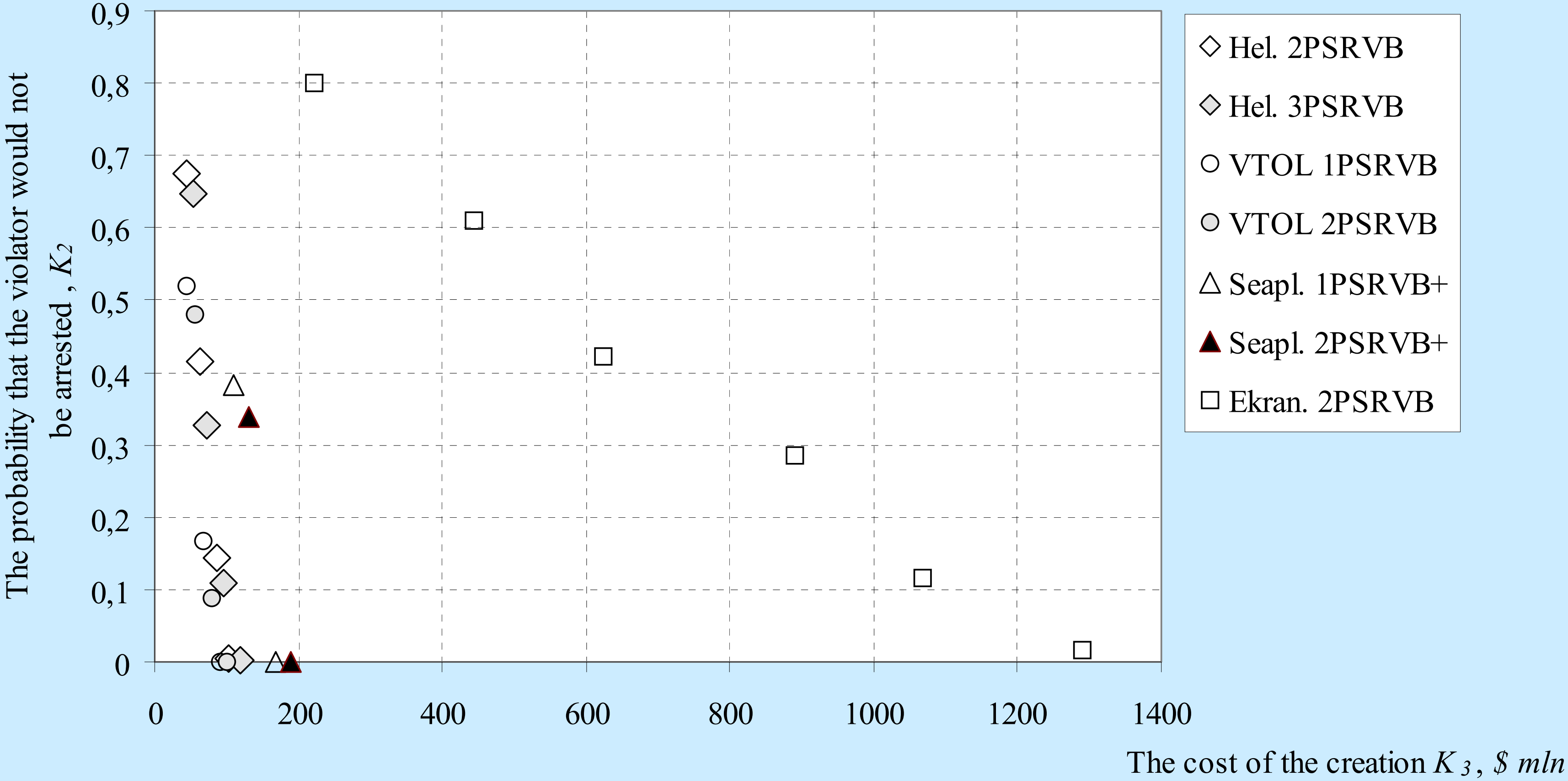

Figure 10. The probability that the violator would not be arrested K_2 as a function of the cost of creation of the CGS air component K_3 (the region of Kuril Islands)

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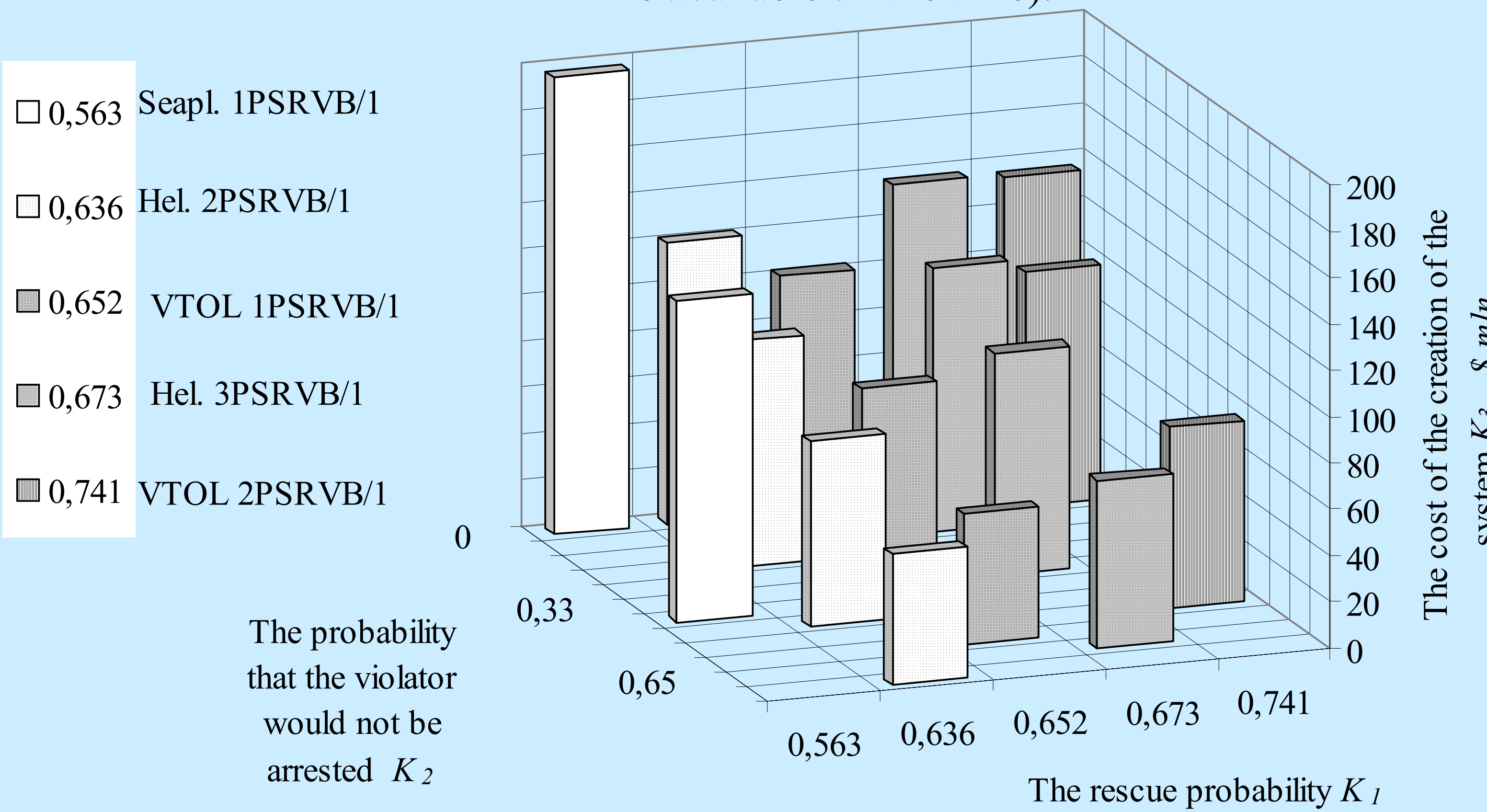
Figure 11. The rescue probability K_1 and the probability that the violator would not be arrested K_2 as functions of cost of creation of the CGS air component K_3 (the region of Kuril Islands, the information about RO location is available all the time).



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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_{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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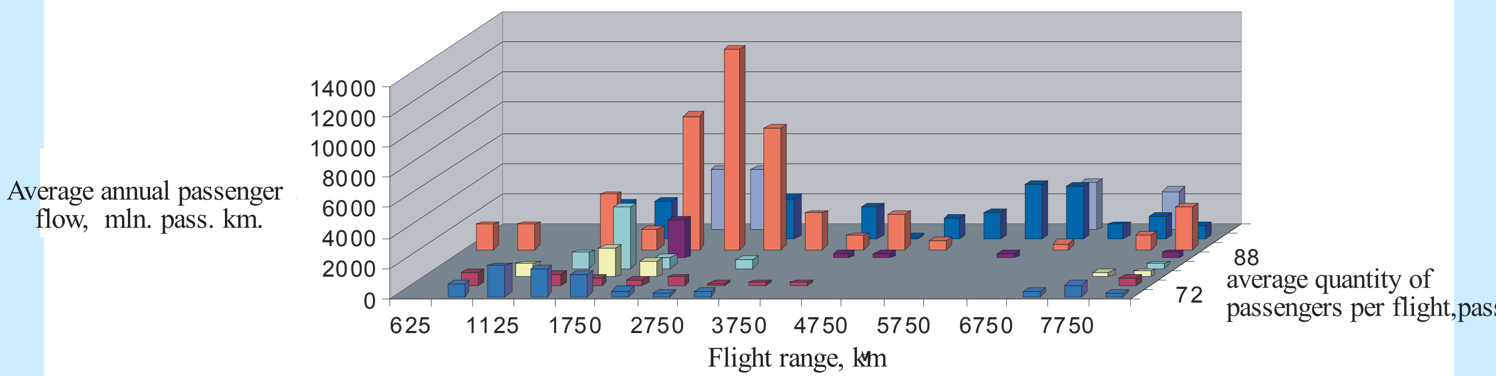
Initial data

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

	Range of passenger air transportation , km																			
	0-250	250-500	500-750	750-1000	1000-1250	1250-1500	1500-2000	2000-2500	2500-3000	3000-3500	3500-4000	4000-4500	4500-5000	5000-5500	5500-6000	6000-6500	6500-7000	7000-7500	7500-8000	more than 8000
0-6	41	119	134																	
6-10	24	24	273	131																
10-14		41	139	319	115															
14-18		27	114	96	458	583														
18-22		33	65		110	174	1339													
22-26			105	152	91	216	716	1230												
26-30		50	132	282		202	282	897	1150											
30-34		39	36	76		47	154	58	1186	898										
34-38		64	47	136	50		118	137	156	1298	461									
38-42			171	129	53	121	390	220	83		946	342								
42-46			207	82	64		292	422	196	317	114	838	220							
46-50			454	225	222	77	81			231		137	901	257						
50-54			422	205	83	84	180	365	332	249				552	180					
54-58				192	718	108	309	104	117		152				419	427				
58-62				476	575		455			147					196	248	400			
62-66					1003	588	355	463		304	163						755	273		
66-70					290	842	1413	403	427									401	517	
70-74				810	1970	1751	1368	359	174	335								273	744	188
74-78				910		722	537	404	609	198	207	209								518
78-82					862		1916	998											300	331
82-86						1003	3995	649		529										268
86-90								2519				287	292			316				380
90-120			1580	1600		3604	1318	8798	13172	7972	2316	842	2257	579			384		910	2800
120-150						2356	2564			2709		2167	125	1412	1744	3674	3509	954	1575	918
150-200								4044	4056								3151		2601	

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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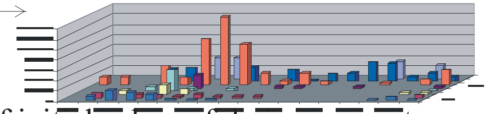
Aircraft fleet creation algorithm

Initial data - demand



Selection of initial values of design parameters and variables

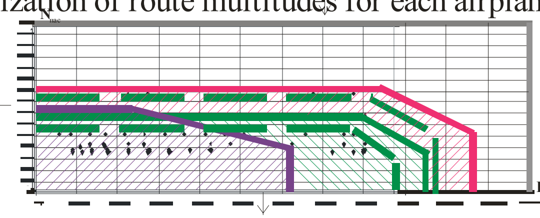
	B777-200	Ил-96м	A330-300	Ил-86	A340-200	Ил-96-300	A300-600R	B767-300ER	B757-200	Ту-204-220	Ту-214
$N_{пас}$, [redacted]	375	370	353	350	321	300	296	269	212	210	210
L_p, км	10000	10400	8600	4350	12400	9250	7240	8800	5980	6350	6350
$m_з$, т	267,6	270	217	215	257	230	165	186,88	108,8	110,73	110,75
[redacted]$_{пуст}$, т	140,6	132,4	118,17	115,86	123	119	90,1	88,18	58,5	59,5	59
$V_{кр}$, км/ч	886	850	870	850	870	850	828	850	850	830	830
$H_{кр}$, м	11000	11600	10000	11000	12000	11000	10670	11887	11890	11500	11000
$N_{кр}$	9	9	9	9	9	9	9	7	6	6	6
$P_{кр}$, кг/м²	613	689	574	570	708	617	635	660	587	651	607
$N_{ппс}$, чел	2	3	2	2	2	2	2	2	2	3	3
[redacted]	2	4	2	4	4	4	2	2	2	2	2
$C_{р.д}$, кг/даН*ч	0,35	0,5	0,35	0,54	0,4	0,38	0,36	0,4	0,4	0,38	0,595
[redacted]	4,4	5	5,2	1,6	6,1	4,4	4,7	4,4	4,9	4,4	5
P, т	2*39,5 P 4084	4*17,03 Pw2337	230,6 CF6-80E1	4*13 НК-86	[redacted]	4*16 ПС-90А	[redacted]	[redacted]	[redacted]	2*17,3 Pw2037	2*16,14 ПС-90А

m_o, т	$m_т$
$S_{кр}$, м²	$m_{т\ max}$
λ	$m_{пуст}$, т
c_o	$N_{ппс}$, чел
	$P_{кр}$, кг/м²
$\lambda_ф$	kd
$H_{кр}$, м	γ, млн у.е./т
$V_{кр}$, км/ч	kdr
$N_{кр}$	Pp
$N_{пас}$, чел	Mp
η	$C_{рд}$, кг/даН*ч
L_p, км	P, т
$m_{цн\ max}$	P_t
L_{max}, км	TV

Optimization of performance and parameters by the following variables

Ж$H_{кр}$, м
Ж$V_{кр}$, км/ч
ЖP, т
Жm_o, т
Ж$S_{кр}$, м²
Жλ
Жχ
Жc_o

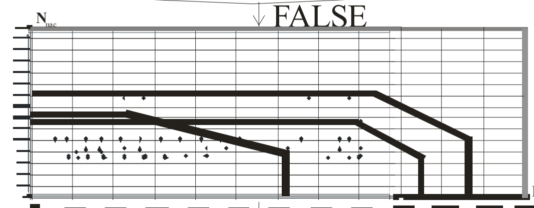
Optimization of route multitudes for each airplane type



TRUE

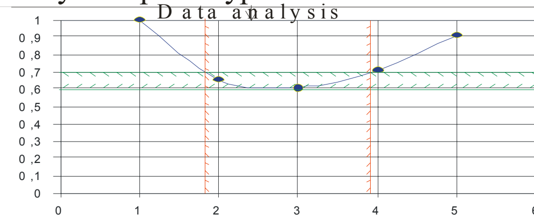
The quantity of aircraft types in the fleet is smaller than the given number

FALSE



Variation of quantity of arplane types within the fleet from 60 to1

Data analysis



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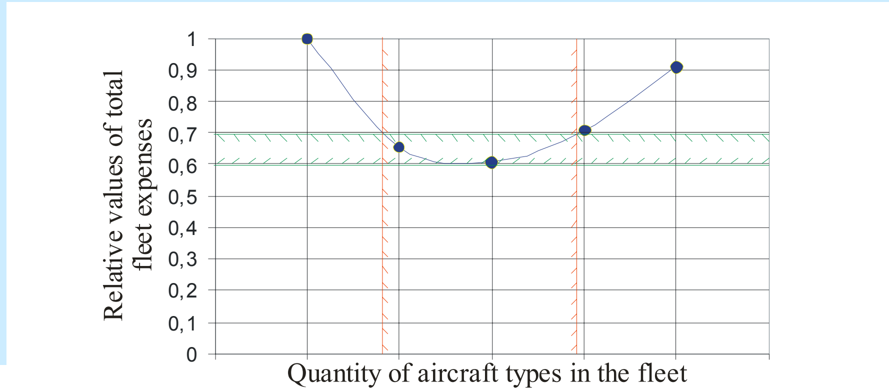
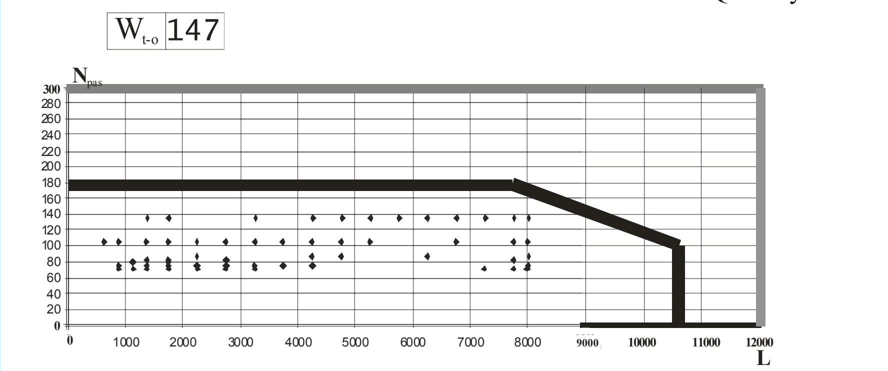
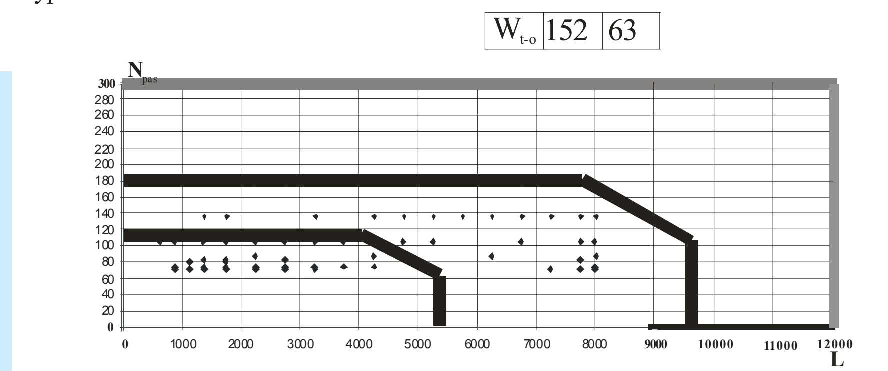
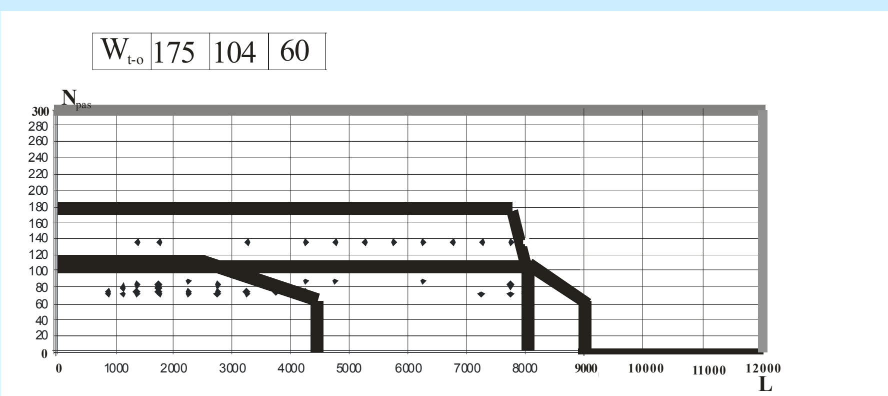
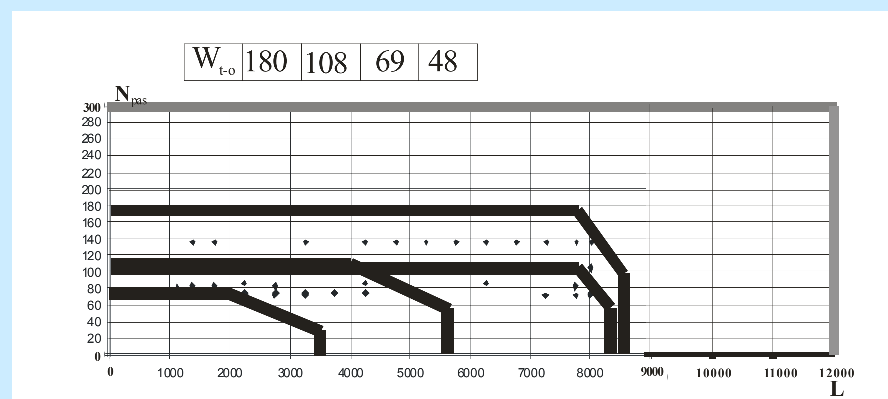
Analysis of the derived data











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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;

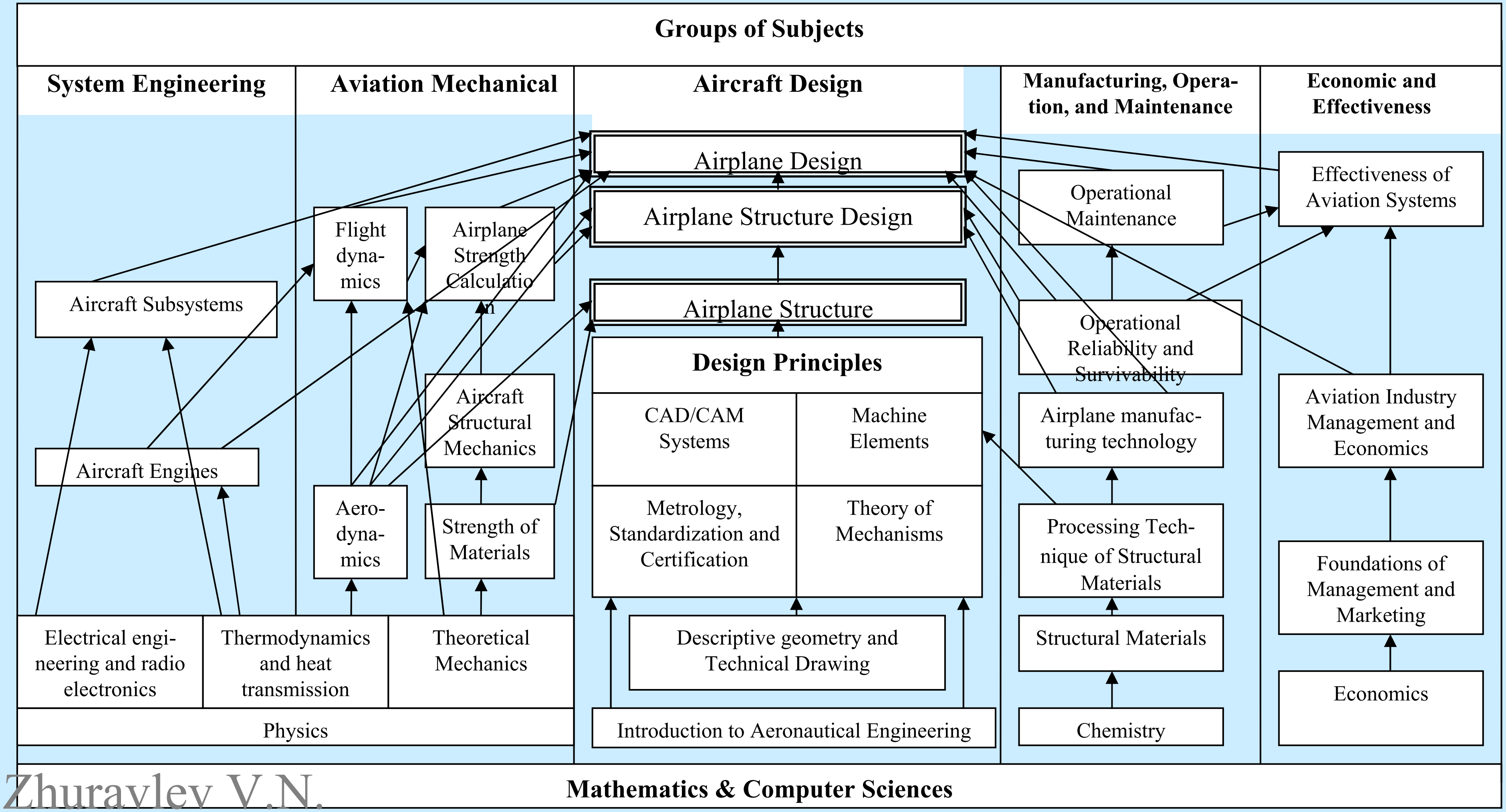
We teach specialists in the field of Design and Operational Effectiveness of Complex Aviation Systems;

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.

The curriculum structure for specialty “Airplane Design” (Engineers (Masters) Degree in MAI)

(without liberal arts)



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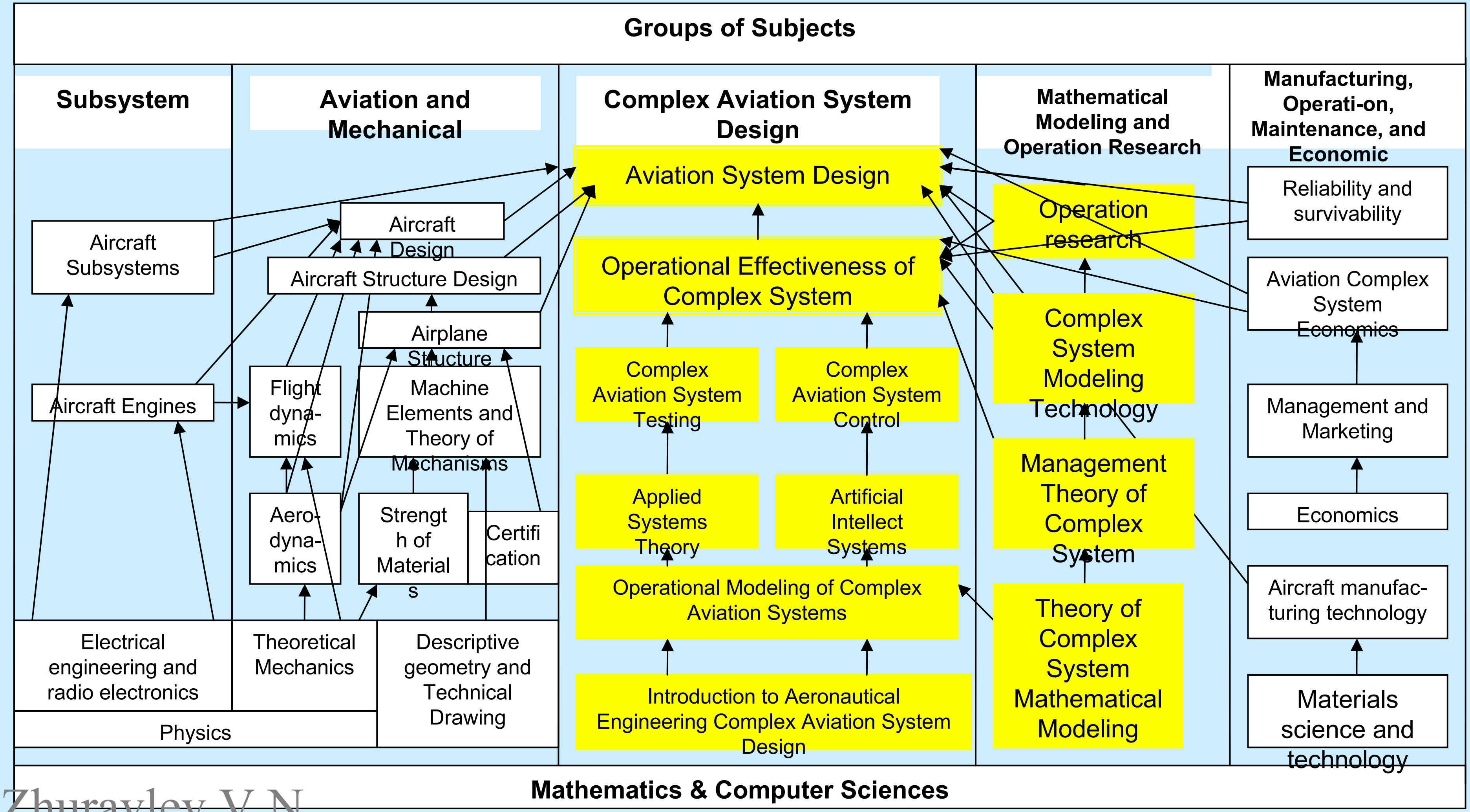
The curriculum structure for specialty “Design and Operational Effectiveness of Complex Aviation Systems” (Engineers (Masters) Degree in MAI) (without liberal arts)



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