ON THE MEDIUM OF FORMING ADVANCED SPACE PROGRAMS

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Summary

The report is dedicated to the analysis of essential properties specific to the rocket-space designing medium, providing for a high productivity team-work on the system project phase.

Formulated are sufficient informative conditions for comparison and selection of a future space program reasonable alternatives with regard for the total risk forecast.

Those conditions concern instruments such as models of products under creation, life-cycle phases, space activity and program management infrastructure, dynamic medium of a program realization: service market, state of a program accomplishment subjects, materials, technologies etc.

The ability to obtain adequate picture over mutual influence of a space program and the dynamic medium is essential.

The analysis run tool utilizing the methodology of arriving at a decision under uncertainty conditions and a given goals hierarchy is bound to provide for input data validation, procedures verification and interactive analysis and selection mode.

Certain conditions of international cooperation expediency when realizing sophisticated expensive programs are considered.

In this connection it is noted the necessity for interdisciplinary integration assuming use of data from linguistics, semiotics, logic, information theory with the aim of both adequation of international scientific-technical terminology, improvement of machine translation systems, and solving more general problems within the range of data transfer and processing, functional semantics, programming, different sign systems optimization.

The statement of the problem actuality is demonstrated by the example of forming future Space Transportation Systems (STS).

l. Introduction

The progress of the rocket-space technology development in the new century is much dependent on a future transportation system outlook and its main consuming performance: specific cost and reliability of cargo insertion (retrieval), its possible "quanta" and transport conditions. Efforts through the last decades on perfecting space transportation systems all over the world cannot be proved successful.

Application of expendable launch vehicles is of low effectiveness not only due to circulation of manufacturing failures risk but as well owing to a great construction risk (especially integrating failures risk) manifesting itself in the course of the first launchings of most new or much up-dated expendable vehicles (see table 1).

Operational practice of partially reusable shuttles did not come up to expectation either on economics or on risks.

Authors of the present report sufficiently long perceived the actuality of considering those factors and thus the content of the report is the logical extension of the formerly presented results[1,4].

In the framework of the Rosaviakosmos "Oryol" and "Grif[1] programs different versions of launch vehicles development including the reusable ones have been formed and compared (see table 2). Criteria for comparison and selection of preferable variants have been formulated, consideration of risk factors when comparing the variants has been shown actual as well as the influence of a cargo traffic volume, sequence and terms of new systems development beginning, structural and technological succession of systems on the results of comparison (see table 3,4).

In the framework of Russian "ORYOL" programme[1] alternative variants of future reusable space transportation systems (RSTS) based on the technologies of different newness levels are under study.

The highest technological succession from traditional expendable launch vehicles (ELV) and therefore the least creation risk are realized within the variant of partially reusable omniazimuth launch vehicle (ROLV)[2] of vertical take-off composed by the reusable fly-back booster (FBB) of the first stage and the second core stage (CS).

New technologies manifest in the variants of fully reusable two-stage or single-stage systems of vertical or horizontal take-off which seem to be promising in the matter of operational cost effectiveness but venturesome in the sense of development cost starting from the mandatory requirement of reaching warranted success in executing a space transportation program.

In the report the attempt is made to refine these qualitative findings by means of the present- day risk management technologies through the RSTS life-cycle phases.

The risk analysis for fully reusable systems is conducted taking example by the single stage reusable space rocket-plane (RSRP) of vertical take-off and horizontal landing such as the American "Venture Star" concept.

2. General scheme and fundamentals of validating decisions under conditions of uncertainty.

In the course of realization of space projects when moving forward through main life cycle phases, refinement of an article design parameters, validation and verification of basic principles of structure and technology, development of maintenance and operation methods occur. Nevertheless, through all life cycle phases design principles are followed under conditions of a great uncertainty in respect to technical-operational performance of an article under creation and primarily in respect to its reliability, service life and safety. Procedure used in this work allows the uncertainty level of a problem to be formalized and connected with the levels of losses and additional expenses needed for reaching the guarantied result of a program realization[3,4].

Figure 1 shows the general scheme of the study including the following steps:

statement of the problem (formalizing of a goal, conditions and strategies of reaching the goal);

arriving at a decision (formation of a model and selection of the strategy leading to the goal);

realizing the decision (treatment of data when realizing the selected strategy and validation of operational decisions specified by that strategy).

Figure 2 illustrates three used in this case principles of validating decisions and three types of strategies for reaching a goal under conditions of uncertainty:

the principle of guarantied result and the corresponding assuring strategies (absolutely or practically with the stated level of guarantee);

the principle of stochastic determinism allowing the guaranties of reaching goals to be achieved due to the stability of the accidental phenomena set (so called fractional strategies);

the principle of consecutive removing uncertainty recommending to use flexible (self-learning, refining) strategies when the adequate fractional strategies cannot be proposed for lack of data.

The employment of the procedure allowed to single out areas of values of the rocket technology operating programs volumes (namely, finely- serial or pilot production) where the assurance of a successful program realization based on a direct experimental confirmation of probability indices is non-effective. For unique space programs the way out obviously lies in indirect confirmation of possibility to provide for the required guaranty level by means of estimated-experimental method based on the overall experience of engineering and valuation of effectiveness of measures and means specified in reliability and safety provision programs. The total risk model is the methodical background of the approach.

3. Total risk model

The total risk model is set up on the basis of actual experimental data (test and operation results) for native and foreign launch vehicles. In so doing data on 3800 launchings of 50 launch vehicle types of Russia, USA, Europe, China, Japan (among them data on 250 accidents) are used.

Main steps and results of building the total risk model.

On the first step launch vehicles and their structural elements are classified through the features of size, technological perfection and newness. Heredity relations over the classes of launch vehicles, booster stages, upper stages and engines are established.

On the second step all features of launch vehicles and stages are classified over the nature (constructional, manufacturing, operational) and their manifestation probability within one flight or several flights under the following ranks: reliable, potential, infrequent. As a result of the analysis and treatment of statistics for every analog rocket total number of the identified failure sources and their distribution upon manifestation probability over every failure type are estimated.

On the third step averaging through all analogs in every class gives estimates of predicted potential failure sources number of different nature and their distribution upon manifestation probability. For every rocket sample and its

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launching item numbers (applied to reusable articles) total manifestation probability of one from potential failure sources can be estimated. It is this probability that determines total failure risk in a particular flight.

On the fourth step total risk model parameters are refined when new data on analog rocket launchings, on-ground and flight tests results for the rocket under study are available.

On the fifth step summary data can be given in the form of risk contours reflecting dynamics of a failure probability variation depending on item numbers of sample, flight, ignition in time and on track of a flight.

The principal feature of the total risk model for reusable launch vehicles is in that the rate of removing constructional risk for reusable articles is larger than that for expendable ones and the rate of removing manufacturing risk is less (circulates over less sample numbers), the most part of manufacturing risk for every sample being removed in early flights. Constructional and manufacturing failures of reusable articles can strongly limit the predicted average service life of reusable articles and sacrifice the expected cost effectiveness due to an increase in technical service life.

Simplified reliability model assumes a reusable article loss risk to be characterized by the constant value of Q = 1-P and this one limits the reusable article actual service life (M_{as},) to the level of

$$\mathbf{M_{asl} = P\ (1 - P^{Mtsl})\ /\ Q} \qquad \mathbf{(1)}$$

where P - probability of failure-proof operation;

M_{tSl} - technical service life when reaching of which the article operation is finished.

The model of total risk refines that the loss risk is the highest for the first samples upon early launchings as well as upon launching item numbers close to the technical service life. It is early failures that significantly reduce an expected service life of first reusable articles samples and enlarge the dispersion of predicted actual service life estimates. On the basis of the estimates a potential effectiveness of fractional strategies in the circumstance and an expedience of the further increasing operational reusable elements number are verified. Besides an expedience of manufacturing pilot FBB and RSRP samples for working up inter-flight maintenance and repair technologies is evaluated.

These features are taken into account when comparing the advanced launch vehicle concepts.

4. Comparative analysis of the launch vehicles' costs considering total risk

Comparison of the advanced launch vehicles' costs has been carried out on the basis of the anticipated cargo traffics under the Federal space program (including commercial launches) until 2035 over the 5 to 25 tons range of payload masses with maintenance operations left out of account. The anticipations have been obtained in the framework of Russian ORYOL program.

Prediction of expenses assuring the cargo traffic program accomplishment is given for the guaranty level of 0.997.

Basic Option 1 assumes to realize the cargo traffics with the ELVs of "Soyuz", "Zenith", "Proton".

Option 2 suggests the development until 2010 of the ROLV replacing the "Zenith" and "Proton" launchers.

Option 3 suggests the development until 2010 of the RSRP replacing all ELVs within the cargo capability range considered.

For Options 2 and 3 optimal (considering risk) service life of ROLV and RSRP reusable elements are defined.

Table 4 shows the relative results of preliminary cost estimates for the considered options of a launch vehicle system structure where the total life cycle cost (with allowance for the total risk) for Option 1 (only ELV operation) is taken for unit.

It is evident that the consideration of total risk fundamentally modifies the chart of Options 2 and 3 comparative operation cost effectiveness: potential operational advantages of RSRP are not realized, and the life cycle cost of Option 3 (RSRP) is roughly twice as large as of Option 2 (ROLV).

Thus, the total risk management is one of the principal factors of RSTS development planning. Actually, cost effectiveness estimates carried out not taking that factor into account are no use especially when new non-sumpled technologies are in question (see fig.3).

Proceeding from the assumption that space projects in the long term will prove international in character, it is important for the participants to agree on the means of communication. The existing criteria of making this choice may undergo change in future. It is not impossible that an artificial language with preset parameters may eventually emerge to become among other things a go-between in computer translation. In any event, it is important to optimize methods of teaching the go-between language or languages, standardize the terminology, T

set to right acronymic and improve machine translation programs.

The problems in question are impossible to resolve without making use of the experience gained in the field of the general theory of linguistics, modelling speech activity, normalizing language systems or without inter-linguistics.

Interdisciplinary connections also acquire importance, since manning an object, including a space object, implies the use of sign systems that are impossible to be set to rights unless they are based on a complex of disciplines that are focused on a language, - a universal sign system. With time the user will perceive increasingly more information from the language environment, which will entail the creation of effective ways to set it to rights, as well as to codify and decode it. In this context it would seem useful to rely on the principles of semiotics, linguistics, information theory and psychology to establish an optimal correlation between the object of denotation, denotation and man (described in terms of linguo-semiotics as semantics, syntactics and pragmatics), and also to determine the admissible information redundancy limits in syntagm and paradigm to minimize the risk in the "user - sign system - manned object" succession.

In recent decades linguistics has made great strides in studying the language structure and system both in theoretical and applied aspects. Fundamental structural and functional analogies have been discovered between the sign- and non-sign systems that are studied by biology, physics and mathematics. Results of this kind of interdisciplinary studies may prove useful in improving methods of systemic analysis, used to draw up promising space programs, including at the task formulation stage.

References

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[2] S.F. Kostromin, A.M. Romashkin, G.V. Efanova. *Study On Validation Of Design Principles Of The "Oryol" Space Transportation System.* AIAA 96-4491,1996

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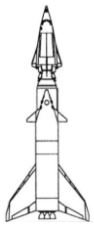
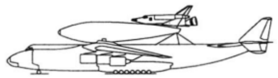
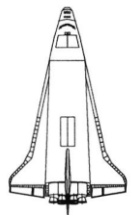
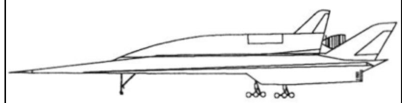
TAB. 1 : Refusals RN, caused mistake to integrations of the complex system

	The Date. Tipe LV. [1] starting LV. The Developer	The Moment of the refusal. The External manifestation. Physical cause of failure	Refused system. Reason defect.	Categorization of the refusal
1	15.08.95. Afina-1. '1. Lockheed Martin.	79s with flight. Has Occurred supernumerary u-turn on corner. On 160 with LV blasted with the land. The Investigation has revealed the refusals two systems LV.	1- stage. Not complex checking are organized for vertical stand.	Integration
2	27.08.98 Delta III[1] 1 Boeing	On 50 fluctuations LV began with flight on corner of the list. At period 55-65 with flight helmsmen units SRM have spent the worker a body at attempt to stop the rotation. In T=72 has operated the system an Self-liquidations. The Inadequate reaction managerial system on small fluctuations LV.	1 stage. S/WCS (incorrect mathematical model)	Integration
3	12.03.2000. Zenit -SL [1] 2 Sea Launch Company	Emergency switching off the engine on 461 sec flight because of stop helmsmen engine 2-y stage in connection with by loss of the pressure in pneumatic system because of logical mistake in algorithm of the automation of preparation LV to starting, allowed in process of her (its) adjustment, called on after previous starting.	The Automation of the preparations to starting LV. Incoordination action personnel at working's	Integration
4	04.06.1996 Ariane 5 [1] 1	1 stage. On 38 with flight has operated the system an of self-liquidation. With 30 with flight by on-board computer protruded the off-design of the command on maximum tumbling sniffled SRM in planes of a pitch and of yaw, but then and on Liquid Propulsion 1-y stage. The Reason: malfunction of software programs allinertial block of gyroplatforms systems to stabilizations. Software of these platforms, created on the base that, which are used on LV "Ariane-4", has not was able adequately to process information on position of the rocket.	CS Disharmony S/W and righting system to dynamics(changes) LV	Integration
5	30.10.97 Ariane 5 [1] 2	Conclusion (injection) of a paying load into off-design orbit, because of off-design rotation LV in the season (term) of activity of 1-st stage(step). The main (basic) cause of anomaly became a rough internal surface of a nozzle called twist of a boundary layer of a propulsive jet of combustion products of the engine with a torque 900 Nm (a nominal complete set of engines of a righting system of a first stage is counted for the moment up to 300 Nm).	Disharmony to actual power of gears of indemnification (compensation) of disturbances to the operational torque.	Integration

TAB. 2: General performance characteristics of the advanced STS concepts considered

STS Concepts	**Concepts based on near-term technologies**		**Concepts based on long-term technologies**	
	ROLV 	**MAKS** 	**RSRP** 	**MIGAKS** 
Number of stages	**2**	**2**	**1**	**2**
Take-off mode	**vertical**	**horizontal**	**vertical**	**horizontal**
Landing mode	**horizontal**	**horizontal**	**horizontal**	**horizontal**
Reusability	**Partial**	**Partial**	**Full**	**Full**
Gross lift-off mass	**550t**	**625t**	**1400t**	**420t**
Landing mass 1st. / 2st.	**52t** **11,5t (Orbital plane)**	**290t (CA)** **21,6t (Orbital plane)**	**141t**	**180t (BA)** **40t**
Engine types 1st. / 2st.	**LRE** **LRE**	**TJ** **LRE**	**LRE**	**TJ+Scramjet** **LRE**
Propellant mass 1st. / 2st.	**187t (H2+02)** **254t (H2+02)**	**84t(kerosene)** **242t (ker.+H2+02)**	**1262t (ker.+H2+02)**	**75t (ker.+H2)** **124t (H2+02)**
Payload up mass (H=200km,i=51deg)	**2 St**	**8...10t**	**18t**	**10...12t**
Payload down mass	**1.5t**	**6.3t**	**lot**	**12t**

TAB. 3: Possible strategies of future STS variants creation and operation

Strategies	Reference life-cycle period, years						
	10	10	10	10	10	10	10
Str. 1	ROLV	$N_L = 2184$					
	ROLV-OTV	$N_L = 390$					
Str. 2	ROLV	$N_L = 992$					
	MAKS	$N_L = 1782$					
Str. 3	ROLV	$N_L = 573$					
	MIGAKS	$N_L = 2247$					
Str. 4	ROLV	$N_L = 724$					
	MAKS	$N_L = 693$					
				MIGAKS	$N_L = 1371$		
Str. 5	RSRP	$N_L = 2765$					
Str. 6	ROLV	$N_L = 873$					
	ROLV-OTV	$N_L = 120$					
				RSRP	$N_L = 1706$		
Str 7	ROLV	$N_L = 349$					
	MAKS	$N_L = 694$					
				RSRP	$N_L = 1706$		

RD&E
Operation
Works don't run

ROLV = Reusable Omniazimuth Launch Vehicle.
ROLV-OTV = ROLV with Orbital Transport Vehicle.
MAKS = Multipurpose Aviation-Space System based on subsonic Carrier Aircraft.
MIGAKS = Aviation-Space System based on hypersonic Booster Aircraft.
RSRP = Reusable Space Rocket-Plane.

TAB. 4: The results of STS life-cycle strategies cost estimates with regard for total risk forecast

Strategies (see tab. 2)	Non-recurring costs		Recurring costs		Total without risks	Risks	Gross total
	RD&E	Ground infrastructure	Manufacturing	Ground support			
str. 1	0.047	0.014	0.874	0.066	1.000	0.019	**1.019**
str. 2	0.091	0.024	0.818	0.065	**0.999**	0.035	**1.034**
str. 3	0.409	0.034	0.312	0.236	**0.990**	0.157	**1.147**
str. 4	0.473	0.044	0.495	0.169	**1.181**	0.159	**1.340**
str. 5	0.316	0.084	0.290	0.307	**0.997**	0.104	**1.100**
str. 6	0.362	0.098	0.544	0.215	**1.219**	0.126	**1.345**
str. 7	0.407	0.108	0.468	0.214	**1.197**	0.130	**1.326**

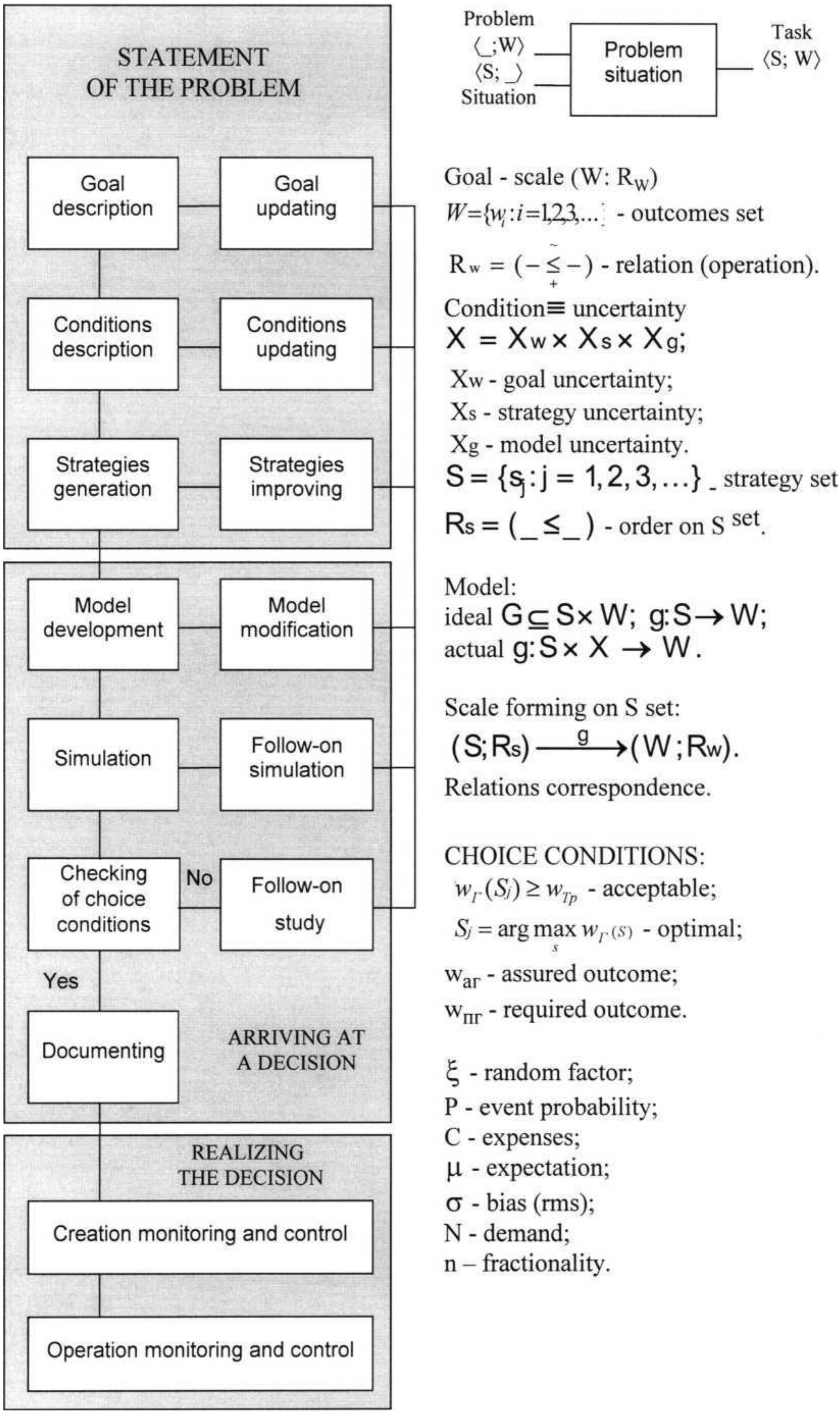


FIG. 1: General scheme of the study

1. PRINCIPLE OF GUARANTIED RESULT

GUARANTEE

ABSOLUTE

$$w_{A\Gamma} = \inf_{x} g(s,x) \quad (\forall x \in X)$$

PRACTICAL (β-level)

$$w_{\Pi\Gamma} = \inf_{x} g(s,x) \quad (\forall x \in [\underline{x}(\xi), \overline{x}(\xi)]),$$

where $[\underline{x}(\xi), \overline{x}(\xi)]$ - β-confidential interval

2. PRINCIPLE OF STOCHASTIC DETERMINISM

FRACTIONAL

For $P_i = P_j^{1/n}$

$c_i = \frac{1}{n} c_j$

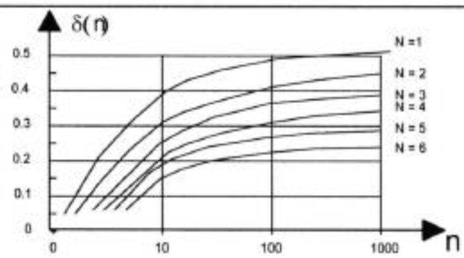
random event

n- fraction

$$\beta = \sum_{m=N}^{N_\Gamma} \binom{N_\Gamma}{m} P_i^m (1-P_i)^{N_\Gamma - m}$$

$$C_\Sigma = N_\Gamma \cdot C$$

$$\delta = \frac{C_\Sigma - C_{\text{Др}.\Sigma}}{C_\Sigma}.$$



STRATEGIES

For $m_i = \frac{1}{n} m_j$

$c_i = \frac{1}{n} c_j$

random values

$\frac{\sigma_i}{m_i} = \frac{\sigma_j}{m_j}$

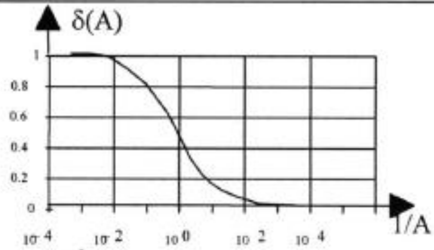
n-fraction

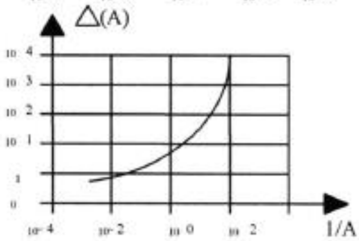
$$N_\text{д} - t_\beta \cdot \frac{\sigma_i}{m_i} \sqrt{N_\text{д}} - N = 0$$

$$A = \frac{t_\beta^2 \cdot \sigma^2}{m^2 \cdot N}$$

$$\delta(A,\infty) = \frac{1 + \sqrt{1+4A}}{2A + 1 + \sqrt{1+4A}};$$

$$\Delta(A) = \frac{C_\Sigma - C_0}{C_0} = \frac{1}{2}(A + \sqrt{A} \cdot \sqrt{A+4});$$





3. PRINCIPLE OF CONSECUTIVE REMOVING UNCERTAINTY

FLEXIBLE - STRATEGIES

for two-alternative decisions

$d(x): X_n \to D;$

$D = D_1 \cup D_2;$

$\dim X_n = n;$

$P\{\theta_1\}; P\{\theta_2\};$

$P_{ij}, C_{ij}, i,j = 1,2;$

$M[C] = \sum_{i,j} C_{ij} P_{ij}.$

Model:

$$M[C] = M[C_0] + P\{\theta_1\} \cdot (C_{12} - C_{21}) \times$$
$$[1 - \int_{X_n^{(1)}} f(x/\theta_2 \exp\{I(\theta_1 \to \theta_2; x) - h\} dx]$$

where:

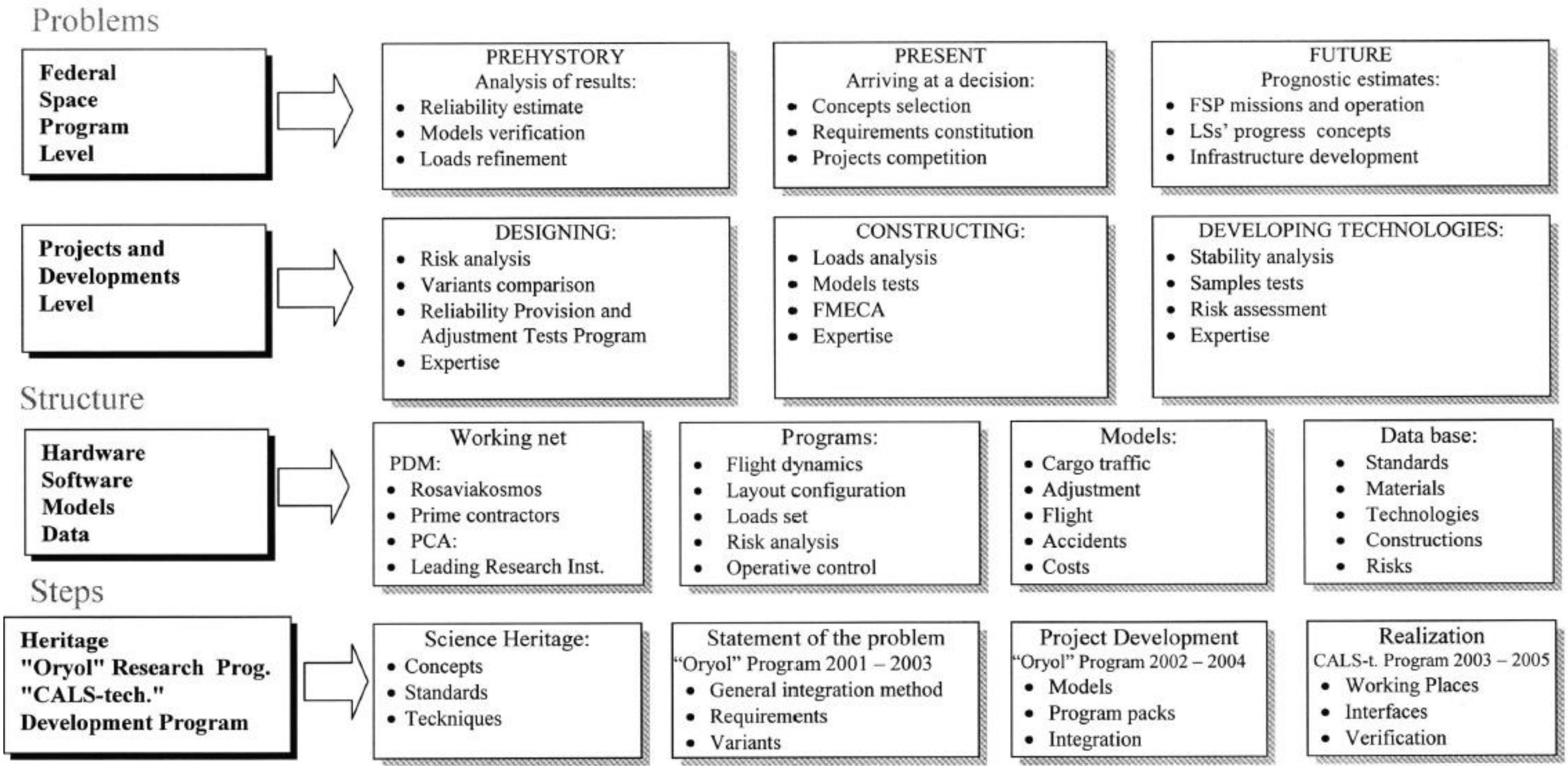
$M[C_0] = P\{\theta_1\} \cdot C_{11} + P\{\theta_2\} \cdot C_{22}$ losses without errors;

$I(\theta_1 \to \theta_2; x) = \ln\left(\frac{f(x/\theta_1)}{f(x/\theta_2)}\right)$ measure of differentiating;

$h = \ln\left[\frac{P\{\theta_1\} \cdot (C_{21} - C_{22})}{P\{\theta_2\} \cdot (C_{12} - C_{11})}\right]$ discriminator;

$\eta = M[C_0] / M[C]$ information efficiency.

FIG. 2: Principles of validating decisions



LS - Launch System PDM- Persons Decision-Makers PCA - Persons Carrying out Analysis FSP - Federal Space Program FMECA - Failure Marginal Essentiality Consequence Analysis

FIG 3: Future launch systems creation. Development of integrating cals-technologies for science-technical support