Slide 1

S1. Strategy for success. Recommendations

The current Power Point Presentation (PPP) presents information based on:
- My own knowledge/ experience;
- Experience of spacemodeling leaders, especially members of the Russian national team;
- Some ideas / techniques / etc., which I can implement in models, given time to will design, build, test, and compete.

Some of the information already has been posted several years ago on the web-site of the Rocket Modeling Sport of the Russian Federation www.frms.ru.

The current PPP provides a more complete, updated and much more visual version of the topic.

S1 event expresses the quintessential nature and symbol of the spacemodeling slogan «Higher, Higher and Higher!» And in some ways S1 is the most representative of the sport.

Really, what question would an outsider ask when he/she sees a rocket mode for the first time? The most likely one would be: “How high does your model go?” He wouldn't ask, “How long this model will coast?”

In all other events (except for S7), ALTITUDE is one factor among others contributing to the results and success. But in S1 category ALTITUDE IS the RESULT, in the pure form.

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Forward Notes

4. This data is based on wind-tunnel test results. Yes, most likely the tests were conducted on models with larger dimensions than we have in our models (with the greater values of Re Numbers). However, as the proof of applicability (to some extent) the same method and the mathematical models have been used at the Minakov School for many years.

“Flight Dynamics of Missiles” is the classic in the field of rocket flight dynamics, and particularly in the area of the rocket aerodynamics.

This book is not only the result of theoretical research. What makes this folio really valuable is that much of the data is obtained from real life experiments.

For a few decades this folio has been one of the prime reference books for Soviet / Russian engineers and specialists in the field of missiles design / manufacturing.

6. The presented version of the material (Rev. 4.) has some additional information and changes made to the previous version (Rev. 3.).

List of changes presented at the very end of the PPP.

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1.1. Numerically simulated model of Cd_{total}

I do not describe the entire math behind the numerically simulated model of the Cd_{total}, which was used for numerical analysis. It is generally known.

However, I am going to present some of it.

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1.1.1. Aerodynamic skin friction coefficient Cf

Graph data on **C_f = f (Re, X_t)** from «FDoM» and from US source are essentially the same data. However, the last has a wider Re range, and what is more important, includes data for **X_t=0.8**, from a range of substantial nonlinearity of **C_f** vs. **X_t**, which is important for analytical interpolation of available data.

* - Note, that values of Skin friction coefficient from «FDoM» **(2 C_f)** are related to both surfaces of a plate, and values of Skin friction coefficient from US source are related to one side.

I approximated these graph data into approximating analytical dependence (very close to primary sources – see Graphic interpretation of the approximation and comparison with primary source data (next slide)), which simplify parametric analysis for wide (and applicable for our models) range of Re numbers (10^5 – 10^8) and for different values of transition location **X_t**.

Smaller Re values will correspond to insignificant velocities, and therefore even if there will be a divergence between approximation and a real value, it will not affect value of drag force. S1 models do not have bigger than **Re =10^8** (and even **Re >10^7**) values.

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1.1.1. Aerodynamic skin friction coefficient Cf (Con't)

Obtained analytic approximative dependence (2 C_f) vs. Re and X_t is given by:

(2 Cf) = f (Re, Xt) = 10^A (lg (Re)) ^ (-10^ (B)),

Where coefficient A and B:

A (Xt) = 2.5901* Xt ^6 + 2.7736* Xt ^5 - 8.1228* Xt ^4 + 5.0157* Xt ^3 - 0.5402* Xt ^2 + 0.8645* Xt + 0.0316

B (Xt) =-1.2564* Xt ^6 + 4.1179* Xt ^5 - 4.2629* Xt ^4 + 1.7633* Xt ^3 - 0.1676* Xt ^2 + 0.2059* Xt + 0.4252

Represented approximative dependence for (2 C_f) values is valid for calculation of:

- body's aerodynamic skin friction (don't forget to take into account (divide by 2), that results are given for doubled wetted surface),
- fin's aerodynamic skin friction.

It was suggested for all cases in the analysis provided below that transition location for fins Xt =0.8, in order to consider obvious turbulence in a root chord region - a region of fin-to-body junction.

Though in reality, for a nonplanar biconvex profile a transition line (point on a chord) most likely coincides with a maximum thickness line. And Xt should have even smaller value. But also Xt coordinate depends on Re number (i.e. flight velocity and fin's size). However, these complications are omitted in the analysis provided below.

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1.1.1.1. Location of Laminar-to-Turbulent flow transition point X_t

Laminar flow becomes unstable with increase of velocity, and it transfer into Turbulent flow at some Re number, called critical (**Re_t**).
As you can see at **$C_f = f(Re)$** plot, the value of a/d friction coefficient **C_f** is significantly vary with (and might differ by several times) regime of flow, laminar (**$X_t = 1$**); turbulent (**$X_t = 0$**) or transition **($1 > X_t > 0$),** i.e. vary depending on Location of transition point **X_t**.

On top of that, some factors bring into flow additional disturbances, destabilizing it. That result into earlier flow turbulation by:
- Location of Laminar-to-Turbulent flow transition point **X_t**
- Flight velocity.

Factors, affecting location of Laminar-to-Turbulent flow transition point X_t (critical Re value (Re_t)):
- External **surface roughness**;
- **Single surface asperities**: body's Generating line’s kink / surface matching / overhang / groove / joint etc. at the top (nose) part of the rocket (particularly groove at the body-NC juncture);
- **MICRO-waviness** and **MACRO-waviness** of external surface.

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1.1.1.1.1. Impact of a surface roughness onto critical Re value

Professor of Moscow aviation institute Lev Chernobrovkin in his book “Flight Dynamics of Missiles“ provided data for critical Re values as function of surface roughness (which is similar to the data in the presentation of Chris FLANIGAN).
On ordinate axis - critical Reynolds number.
On X axis - product of Re of the body and relative height of roughness peaks **h /L** (**L** - body's length).
Graphical interpretation of the approximations (for numerical analysis) based on this data is also presented.
The linear dependence **Re_t** vs. **M** between curves for **M=0** and **M=1** was assumed.
Obtained approximations for **$Re_t = f(Re((h/L), M)$** is omitted here due to their awkwardness.

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1.1.1.1.2. Impact of single surface asperities onto critical Re value

Graphical data for critical Re values as function of dimensions of single surface asperities (body's Generating line’s kink / surface matching / overhang / groove / joint etc.) at the top (nose) part of the rocket is provided from “FDoM”
On ordinate axis - critical Reynolds number.
On X axis - product of **Re** of the body, **(h/L)** and **(h/B)**.
Where **h** and **B** – height and width of groove or flange.
Graphical interpretation of the approximations (for numerical analysis) based on this data is also presented. The linear dependence **Re_t** vs. **M** between curves for **M=0** and **M=1** was assumed.
Obtained approximations for **$Re_t = f(Re((h/L)((h/B), M)$** is omitted here due to there awkwardness.

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1.1.1.1.3. Impact of surface MICRO-waviness of onto critical Re value

I assume, that surface waviness also destabilizes the boundary layer.
MICRO -waviness might caused by surface' repeated structure. The typical case of such **MICRO-waviness** is a grinning texture of fiberglass through external surface (somewhat macro-roughness).

I guess that the critical Re number (**Re_t**) caused by **MICRO-waviness** might be estimated by value of critical Re number caused by surface Roughness at height of roughness peaks value equal to the fabric's cell depth:

Re_t (MICRO-waviness) = Re_t (surface roughness, $h = h_{cell}$)

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1.1.1.1.4. Impact of the MACRO-waviness of external surface onto critical Re value

MACRO-waviness might caused by thickness differential along a body and by lacquer coat unevenness and by unevenness of a body's surface plaining / grindering / polishing.
I guess that the critical Re number (**Re_t**) caused by **MACRO-waviness** might be estimated by value of critical Re number caused by surface Roughness at height of roughness peaks value equal to the wave's depth:
Re_t (MACRO-waviness) = Re_t (surface roughness, $h = h_{wave}$)

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1.1.1.1.5. Combined effect of the factors, affecting location of Laminar-to-Turbulent flow transition point $X_{t\ sum}$

It is obviously that combined effect of all factors anticipates transition from Laminar to Turbulent flow. i.e. in reality the value of transition point coordinate will fall short of any transition point coordinate value due to independent impact of a separate single factor.
I may hypothesize, that in general case for numerical evaluation of **$X_{t\ sum}$**, the orthogonality conception of separate factors, affecting location of Laminar-to-Turbulent flow transition point can be used:

$$X_{t\ sum} = 1 - ((1- X_{t\ 1})^2 + (1- X_{t\ 2})^2 + (1- X_{t\ 3})^2)^{0.5} ,$$

Where
$X_{t\ 1}$ – location of transition point due to **external surface roughness**;
$X_{t\ 2}$ – location of transition point due to presence **of single surface asperities**;
$X_{t\ 3}$ – location of transition point due to presence of **external surface waviness**

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1.1.2. Nose Cone Cd_{NC}

A. Values of Drag coefficients of the NC (Cd_{NC}) and BT (Cd_{BT}) were obtained from the book “Flight Dynamic of missiles” by Lebedev A.A. and Chernobrovkin L.S., "Mechanical engineering", 1973.

These data based on information obtained from wind-tunnel tests. Yes, more likely the tests were conducted on models with larger dimensions then we have on our models (with greater values of RN). However, the same method and mathematical model was used during many years at the “Minakov’s School”. These data also is presented in his book («Sports scale-models of rockets» by Vladimir Minakov).

$Cd_{\text{parabolic NC}} = f(M, \lambda_{NC})$

Cd for Parabolic NC with Generating line equation:

$\lambda_{NC} = L / (2 \cdot R)$

I was able to approximate Cd_{NC} by simple approximating expression which is linear M- and λ–dependence in the range of M<0.6 (the range of almost all of our FAI models).

$$Cd_{NC}(M, \lambda_{NC}) = (0.00517 - 0.000933 * \lambda_{NC}) * M + (0.0156 - 0.00837 * \lambda_{NC})$$

There is a measurable nonlinearity of Cd_{NC} vs. M for M>0.6. For the range of **0.6 < M < 0.8** the approximating expression changes to:

$$Cd_{NC}(M, \lambda_{NC}) = (-0.012483 * \lambda_{NC} + 0.152417) * M^2 + (0.013225 * \lambda_{NC} - 0.162125) * M + (-0.012374 * \lambda_{NC} + 0.061071)$$

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1.1.2. Nose Cone Cd (con’t)

Cd_{NC} for Parabolic-Spherical NC has been obtained assuming that:

- Pressure distribution along the Parabolic surface (the interval BD) of the Spherical-Parabolic NC (ABD) is the same as along the totally Parabolic NC (CBD) on the interval BD;

- Pressure distribution along the Spherical surface (the interval AB) of the Spherical-Parabolic NC (ABD) is the same as along the body combination “Sphere + Cylinder” on the interval AB.

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1.1.3. Boat Tail Cd

I have approximated a value of Cd_{BT} by a relatively simple approximating expression and formalizing graph data for the range of M<0.4.

The graphical interpretations of the approximations for both conical and parabolic BT are presented as:

$Cd_{BT} = f((r/R), \lambda = \text{var})$

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1.2. Cases under consideration and assumptions

1.2.1. Assumptions: minimum of Cd $_{total}$ (V $_{aver}$) provides maximum of flight altitude

In all cases it wasn't a **MAXIMUM** value **of flight altitude** was considered as a criterion of optimality, but a lower level criterion – **MINIMUM** value **of Cd $_{total}$** at a certain average speed, assuming that the minimum of **Cd $_{total}$** provides a maximum of model's flight altitude, thereby simplifying of a problem solving, and transfering a solving of a problem of rather high level to a solving of a problem of a lower level.

It isn't absolutely correct from the mathematic standpoint, especially considering that values of Cd $_{total}$ are vary with flight velocity (see par. **«1.3.3. Cd $_{total}$ of 2nd stage vs. flight velocity. X$_t$ (V)=const»** and **«1.3.4. Cd$_{total}$ of 2nd stage = f(v) for X$_t$ = f(V). Impact of a surface roughness»**). Nevertheless, the problem's solution (to identify model's optimal geometry) for min **Cd $_{total}$** will be somewhere about problem's solution for max **H $_{flight}$.**

Such a method, which is accepted in the Theory and Practice of Large Technical Systems (aerospace science/industry as well) known as a decomposition method -
to devide a complex problem of a high level into several subproblem of a lower level (and therefore of a lesser complexity), to find a solution for each subproblem, and then to "seam" them. That will reduce time to find a solution for a general problem and will allow to parallelize the process.

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1.2.2. Additivity Concept for Cd $_{total}$ and Cd of the model’s parts

A math simulation model of the model's Cd $_{total}$ is based on the following assumption:
Cd$_{\Sigma}$ equal to sum of model’s elements Cds (NC, body, BT, BS, fins).
It is not entirely correct, especially for Cd $_{BT}$, and Cd back section (Cd $_{BS}$) which depend on a flow “pre-history” and on “what-is-going-on” upstream.
Thanks to Bob Parks’s remarks during the discussion on Rev. 1 of PPP: *“…you cannot really isolate a part of the body and look at it separately from the rest. Its because of the subsonic flow and relatively low Reynolds numbers…”*
However, as a first approximation it is the only way to make an inexpensive and quick comparative analysis (unless you want, able and have time to solve complex airflow system equations, …).

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1.2.3. Location of a Laminar-to-Turbulent flow transition point (Assumptions)

2. In reality a transition from Laminar-to-Turbulent flow doesn't take place at a point, but at some length, where so-called **Transitional flow** occurs with the attributes of both Laminarity and Turbulency. However, engineering models/methods assume (for simplification and universalization – to transfer data of a theoriy and experiments into other similar cases) to "reduce" this length into a point, located in the middle of this transitional flow segment.

And in reality a dimension of this length with a transitional flow mode depends on Re number and on a type of a disturbing factor leading into flow turbulation (body's Generating line’s kink / surface matching / Overhang / groove / joint etc.).
I assume, that presence of several disturbing factors in one place leads into more intensive flow turbulation, and therefore, into a transitional flow shortening, which means a reduction of X_t value.

Therefore, in particular, if a laminar flow turbulation occures as a result of NC-body cylinder junctuire, then a transition location doesn't coincide exectly (in general) with a juncture point of these surfaces, but lies a little lower «down the stream». However, for the numerical analysis it was assumed that these points are coincided.

Certainly It is a "lofty matters". However, it would be advisable to have some perception about the issue.
In this regard, even if a laminar flow doesn’t occur entirely along a model's cylindrical body, nevertheless, some measures for a NC-Cylinder juncture smoothing (see par. **«3.2. Absence of groove/chamfer at the body-NC juncture»**) will be worthy.

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1.2.5. Fins

As soon as we want to determine the model's stability, we have to specify the model's external geometry (in order to predict the Center of Pressure location). We have to be specific in model's the design: the internal geometry; location of all its parts; materials (their densities); the wall's thickness; etc. (in order to predict the Center of Gravity location).

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1.2.6. Model's flight velocities for Cd_{total} calculation

1st stage: **Cd_{total}** was calculated for $V = 40$ m/sec $\approx V_{average}$ 1st stage (*).
2nd stage: **Cd_{total}** was calculated for $V = 80$ m/sec $\approx V_{average}$ 2nd stage (**).
*)
1st stage flight altitude (stages separation point) range $H_1 \approx 60\text{-}80$ m.
For 1st stage engine burn time $t_{burn1} = 1.3–1.5$ sec.
Получаем $V_{aver1} = H_{burn1} / t_{burn1} \approx 40–60$ m/sec
**)
Conciding that models flight altitude range: $H_{flight} = 600–800$ m (certainly for well built models),
2nd stages flight altitude range: $H_2 \approx 550\text{-}700$ m.
Total (burn and coastal) time for 2nd stages, most likely, is about:
$t_{burn2} + t_{coastal2} \approx 6\text{-}8$ sec
Then:
$V_{aver\ 2} = H_2 / (t_{burn2} + t_{coastal2}) \approx 75–90$ m/sec
Obviously, average flight velocity values are varying with initial weight, model's aerodynamic "purity" and it's geometry. Nevertheless, average velocity won't change considerably.
Nevertheless, which velocity should be considered as average? Root-mean-square … or something else?
Fundamentally it shouldn't affect analysis results and their tendencies.

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1.3. Numerical analysis results. 2nd stage

Be aware that analysis results for compared options, presented below IAW described above math. model, and/or carried out by you IAW any methods/software, have errors attributed with accepted assumptions and with any factors omission(s).
An obtained difference in results of compared versions may be within a range of applied methods errors. In these cases results reliability will be low.
However, errors of applied methods aren't always known QUANTITATIVELY.
But it is always necessary to be carefull with obtained numerical analysis results especially if a difference is within a small fraction (a few percents). And to perceive received not as a guidance for execution, but as an additional information. Take into consideration some other factors (for example feasibility)
And if you have a desire and resources, carry out more in-depth studies, including first of all a flight testing.

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1.3.1. Length of the 2nd stage (con’t 1)

2. However, this Cd minimum is gently sloping, and therefore is not sensitive to 2nd stage length changes within the length range under consideration.
And among other things the optimal value definitely lies within accuracy of the applied math model.
Considering the fact that we do not know for certain (at this point) what kind of a dominant flow (Laminar or Turbulent) we observe in the 2nd stage, we basically … don’t have the answer (based on results of the current analysis) to the question “What length is better?”
The answer is … we don’t have the answer at this point And it requires an additional R&D or/and considerations of some other facts, aspects, etc.

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1.3.1. Length of 2nd stage (Con’t 2)

3. For predominantly Laminar flow:
The 2nd stage without BT has a greater Cd_{total} value than the stage with BT, conical or parabolic (approximately 4-3 % respectively greater):
$\mathbf{Cd}_{\mathbf{total}}(L_{BT} = 0) > \mathbf{Cd}_{\mathbf{total}}(L_{BT} \neq 0)$

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1.3.1. Length of the 2nd stage (con’t 3)

4. For predominantly Turbulent flow
However, an interesting and not very expected result is that
the 2nd stage without BT has a lower Cd value than the stage with BT (conical or parabolic):
Let's look at the details of the results for the 2nd stage total body length L sum = 180 mm:
For NO BT: L_{BT} =0; r_{BS} = 9 mm; L_{NC} = 45 mm
For parabolic BT: L_{BT} =29 mm; r_{BS} = 7.2 mm; L_{NC} = 16 mm
For conical BT: L_{BT} =29 mm; r_{BS} = 5.4 mm; L_{NC} = 16 mm

Cd total ($L_{BT} = 0$) < Cd total ($L_{BT} \neq 0$) for both conical or parabolic BT:
for predominantly Turbulent flow (about 9-13% respectively lower).
The reasons behind this interesting result are:
- Despite that Cd base pressure is proportional to contraction ratio (r_{BS} / R) cubed, and in the case under consideration:
(r_{BS} /R)^3 = (5.4 /9)^3 = 0.22 (for conical BT) and …
= (7.2 /9)^3 = 0.51 (for parabolic BT), and therefore Cd $_{BS}$ (for L_{BT} =0) substantially greater then Cd $_{BS}$ with BT,

1. The cylindrical body without BT does not have pressure loss at this ABSENT part, BT:
Cd $_{BT}$ (L_{BT} = 0) = **0** vs. Cd $_{BT}$ (L_{BT} = 29 mm) = **0.027** and **0.059** for parabolic and conical BT respectively.
2. The stage with a cylindrical body (L_{BT} = 0) has a longer Nose Cone and therefore:
a. It has a lesser value of the Cd pressure NC: **- 0.005** vs. **0.009** (Cd pressure NC value for λ_{NC} = 16 mm /18 mm), and more importantly
b. It has a greater area with a Laminar flow and consequently a lesser value of the Cd friction:
0.152 vs. **0.170** and **0.169** for parabolic and conical BT respectively (for predominantly Turbulent flow).

Basically, we have to pay a high price of «3 mm» in the cylindrical part of the stage for every «1 mm» of the BT length in order to meet the «25%» Code requirement. And that will increase the body surface. The stage will have additional friction, which is the lions share in the composition of the total drag.
Or we have to subtract this «1 mm» from a relatively effective NC length.

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1.3.2. Length of 2nd stage BT

Let's find the optimal length division of “25% of the 2nd stage's total length” between NC and BT.
Let's find Cd_{total} values for a few values of L_{BT} = 7.25; 14.5; 21.75 mm.

Will consider L_{sum} =180 mm.
α con $_{BT}$ = α max par $_{BT}$ = 7°
for $(L_{NC} + L_{BT}) = 1/4\ L_{sum}$ = 45 mm

For predominantly Turbulent flow : 2nd stage without BT is the optimal option for a model on an interval of model's flight velosities.

But for predominantly laminar flow «an optimality» is shifted towards 2nd stage with BT.

Thus, it turns out (see results of the analysis of the next par. «**1.3.3. Cd_{total} of 2nd stage vs. flight velocity. X_t (V)=const**»)

1) For predominantly Turbulent flow the more rational (from the point of view of Cd_{total} values) is the 2nd stage option without a BT on an entire interval of model's flight speed.

2) For predominantly Laminar flow:

- for relatively low flight velocities: 2nd stage without BT has a lower Cd_{total} values than the option with BT;
- at some point of velocitiy increase (at about 60 m/sec for the case under consideration): Cd_{total} values for both options (with and without BT) are equal;
- in process of further increase of velocitiy: 2nd stage without BT has a grater Cd_{total} values than the option with BT.

Thus, in order to answer the question «what option is better?», you should to find the answer to the question «What flow mode is taking place on a surface of your model, Turbulent or Laminar?»
And really, will the laminar flow take place at an increased velocity (to the level of 80 m/s (that aproximately corresponds to 2nd stage average speed and to Re numbers > 10^6)?
In order to answer that question you can perform some flight tests (see par. **«8.2.5. Flight Testing to determine body's air-flow regime»**)

Additionally take into consideration for the «BT-No BT» issue the following.
My earlier assumption that an engine extended of the base section will reduce model's drag base was confirmed by Robert Park's numerical analysis of a flow simulation. This information also was presented by Chris Flanigan in his PPP “S1B (Altitude) Results Review“. The analysis came to the conclusion that extended engine (extension length L = 15 mm) will reduce drag base coefficient by at least 16%.

In some way an “Extended Engine” is a poor version of BT. And that fact will advocate additionally for the “NO BT” for 2nd stage-design.

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1.3.2. Length of 2nd stage BT (Con’t)

Conclusion:

1. The question about «BT-No BT» is transferred into a question about flow type on a cylindrical part of the 2nd stage.

2. Clearer wording of the FAI Code, which is forbidding BT, will completely remove this issue.

Nevertheless, there are ways for reduction of model's BS drag even in absence of BT. The idea/concept of a design is described below (see par. **3.3.2. Air flow injecting into body's base region**).

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1.3.3. Cd_{total} of 2nd stage vs. flight velocity. X_t (V)=const

There was an error in given results of the numerical analysis of 2nd stage Cd_{total} in one of the previous versions of this material (Rev. 2.19). The data for all given cases were provided for flight velocity value of V = 40 m/sec, instead of value of V = 80 m/ sec, which is approximately corresponding to average flight velocity of 2nd stages.
However, despite that, almost all conclusions are almost the same for velocity of V = 40 m/sec, and for V = 80 m/sec, except for the comparison of the 2nd stage options with and without BT for predominantly Laminar flow.
For a case of predominantly Turbulent flow the conclusion about irrationality of BT for 2nd stage remains correct for velocity of V = 80 m/sec as well.

Nevertheless, those results of numerical analysis for lower than average flight velocities can be considered as an additional information for overall analysis.
Generally this indicate;
- A complexity of a flow’s nature of it-seems-to-be-a-simple-object as a 2nd stage – just a finned cylinder with a NC;
- You should be accurate and careful with analysis and conclusions, taking into consideration various aspects.

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1.3.4. Cd_{total} of 2^{nd} stage = f(v) for X_t = f(V). Impact of a surface roughness

It was assumed that location of a Laminar-to-Turbulent flow transition point X_t is not vary with flight velocity **V** for cases under consideration at the previous par. (presented graphs **Cd_{total}= f(V)).**

As it was stated in par. **«1.2.3. Location of a Laminar-to-Turbulent flow transition point X_t (Assumption)»** for simplicity of general broad numerical analysis, results of which provided in mentioned below paragraphs (where it was assumed **X_t(V) =const**):

«1.3.1. Length of the 2^{nd} stage»
«1.3.2. Length of 2^{nd} stage BT»
«1.3.3. Cd_{total} of 2^{nd} stage vs. flight velocity. X_t (V)=const»
«1.3.6. NC-loading effect onto Cd_{total}»
«1.3.7. NC-top-rounding effect onto Cd_{total}»

the extream cases were considered:

- fully (or predominantly) **Laminar** flow;
- fully (or predominantly) **Turbulent** flow.

In reality this is not the case (see par. **«1.1.1.1. Location of a Laminar-to-Turbulent flow transition point X_t»)**.

As an illustration of a surface roughness Impact onto **Cd_{total}** the results of numerical analysis of **Cd_{total}** of 2^{nd} stage vs. flight velocity **V** for critical Re value **Re_t = f(V)** (and correspondingly – for a location of transition point **X_t (V)**) are presented.

2^{nd} stage with body's elongation λ **=10** (stage’s length **L = 180 mm**) without tapered BT was considered.

Plot **$Cd_{total\ 2^{nd}\ Stage}$ = f(V)** for 3 heights of roughness peaks values is presented.

(* - It was conservatively assumed, that the height of roughness peaks is measured from the line of the roughness profile valleys, not from the middle base line of the roughness profile. I.e. the height of roughness peaks **h = 2 Rz**)

Heights of roughness peaks under consideration:

1. **h = 0.5 μm**:

Corresponds to 11th grade of finish. **Rz = 0.25 μm** (from the range of Rz = 0.4 - 0.2 μm)
11th grade of finish is achieved by: superfinishing.

2. **h = 10 μm**:

Corresponds to 7th grade of finish. **Rz = 5** μm (from the range of Rz = 6.3 - 3.2 μm (Ra = 1.25 - 0.63)).
7th grade of finish is achieved by: finish grinding

3. h = 20 μm:

Corresponds to 6th grade of finish. **Rz = 10 μm** (from the range of Rz = 10 - 6.3 μm (Ra = 2.5-1.25)).
6th grade of finish is achieved by: pregrinding

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1.3.4.2. Results review

1. **Height of roughness peaks h = 20 μm:**

For low velocity values (fully Laminar flow) the fall of **Cd_{total} (V)** is resulted from the reduction of **Cd_{fric}** (or **C_f**) with **V**, which is a big portion of **Cd_{total}**. And **C_f** is decreasing with **Re** (i.e. with **V**) – see par. **«1.1.1. Aerodynamic skin friction coefficient C_f»**, graph **C_f = f (Re, X_t)** for **M=0)**.
A turbulence is occures at some (critical) velocity, which corresponds to critical Re value (**Re_t**) скрости. And the minimum is occurred at the **Cd_{total} =f(V)** graph.
In reality the occurrence of the turbulence (**$X_t < 1$**) is not coincide with the minimum of **Cd_{total}(V). Cd_{total}(V)** continues to decrease with V. It is explained by decrease of the base drag value, inspite of increase of the friction drag value.
The further intensification of the turbulence on the surface of a model with **V** results in relatively intensive increase of **Cd_{total}(V)**, at which the transition point is shifted to the model's top (**X_t** value fall from **1** to **0**).
This increase of **Cd_{total}** with **V** takes place up to velocity value, at which the flow becom fully Turbulent (**$X_t = 0$**). Occurrence of the maximum on the plot reflects that point. The further velocity increace is accompanied by decrease of **Cd_{total}**, which is related with decrease of the friction coefficient value (see par. «**1.1.1. Aerodynamic skin friction coefficient C_f**»).
Velocity ranges for fully **Laminar** flow (**X_t** =1) and fully **Turbulent** flow (**X_t** =0) are indicated on the **Cd_{total} =f(V)** graph for the height of roughness peaks **h = 20 μm**.

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1.3.4.2. Results review (con't 1)

2. Height of roughness peaks h = 10 μm:

Qualitatively **Cd_{total} (V)** dependence for **h = 10 μm** is similar to **Cd_{total} (V)** dependence for **h = 20 μm**. However, transition into fully **Turbulent** flow takes place at the very end of velocity range under consideration (at **V=240 m/sec**).

3. Height of roughness peaks h = 0.5 μm:

Fully **Laminar** flow remains throughout entire velocity range of **20 … 240 m/sec**.
nevertheless, the plot **Cd_{total} = f(V)** has minimum, имеется минимум, which results from more intence increase of base drag **Cd_{BS}** with **V** than decrease of friction drag **Cd_{fric}** with **V.**

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1.3.4.2. Results review (con't 2)

General comments:

Value of **Cd_{total}** is independent of the grade of surface finish for the velocity ranges of fully laminar **(X_t =1)** and fully turbulent **(X_t =0)** flow.
However, there is a difference in the velocity range of the transition from a Laminar-to-Turbulent flow.
Lesser surface roughness (as well as smaller groove dimension (see results of numerical analysis in the next par. **«1.3.5. Cd_{total} of 2^{nd} stage = f(v) for X_t = f(V). Impact of the body-NC juncture groove dimensions»**)) provides:
- Greater value of critical velocity **V_{crit}** – Flow turbulation takes place at higher velocity,
- Gradient of **Cd_{total}** with **V** has lesser values, i.e. velocity range for which the flow from fully laminar becomes fully turbulent is widened.

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1.3.4.2. Results review (con't 3)

Besides, it is intersting that listed below velocities fall exactly into the velocity range of **50 … 250 m/sec,** which corresponds to the region of the flow transition from fully laminar to fully turbulent (for different levels of the surface roughness – for the considered range of **Rz = 0.25** μm **… 10** μm, which is applicable to our models), and и therefore is the range of velocities with the greater differences in $\mathbf{Cd_{total}}$ values for different levels of the surface:

- stages separation velocity (initial velocity of a 2nd stage), $\mathbf{V_{0\ 2^{nd}\ stage}}$ – about **70 +/- 10 m/sec**;
- presumably average velocity value of a 2nd stage $\mathbf{V_{average\ 2^{nd}\ stage}}$ (~ **80 m/sec**);
- maximal velocity value of a 2nd stage $\mathbf{V_{max\ 2^{nd}\ stage}}$ (or $\mathbf{V_{burn\ 2^{nd}\ stage}}$),
- and therefore includes entire range of 2nd stage burn velocities;
- the most part (and the most significant one) of the coastal velocity range of a 2nd stage $\mathbf{V_{coastal\ 2^{nd}\ stage}}$.

It amounts to that surface roughness has the most possible impact onto the total flight altitude $\mathbf{H_{\Sigma}}$.

The greatest difference in $\mathbf{Cd_{total}}$ values for extreme values of surface roughness for the surface roughness range under consideration (**h = 0.5** μm and **20** μm) is just about 15 % (for values of **V = 100 …140 m/sec**), but that is **NET WINNING**! And I will not advice voluntarily tp abandon this.

In lay terms: 15% of $\mathbf{Cd_{total}}$ in the range of **V** = 100 …140 **m/sec** – I assume, will result in as a minimum of 10% of $\mathbf{Cd_{total}}$ cumulatively for entire flight of a 2nd stage. And it amounts to about 6% of flight altitude.

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1.3.4.2. Results review (con't 4)

4. Progressive increase of $\mathbf{Cd_{total}}$ with increase of surface roughness for taken by itself velocity value

A progressive increace of $\mathbf{Cd_{total}}$ with surface roughness **h** is occurred for taken by itself velocity value (i.e. the second derivative of $\mathbf{Cd_{total}}$ with **h:** $\partial^2 \mathbf{Cd_{total}(h)} / \partial \mathbf{h}^2 > \mathbf{0}$).

Practically, It amounts to that each subsequent equal decreasing of the surface roughness value corresponds to a lesser decreasing of $\mathbf{Cd_{total}}$,

or each subsequent equal decreasing of $\mathbf{Cd_{total}}$ may be achieved by increasingly higher cost.

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1.3.4.2. Results review (con't 5)

5. Paradox of an existence of the $Cd_{total}(h)$ curve minimum

The paradox of an existence of the $\mathbf{Cd_{total}(h)}$ curve optimum (minimum) on **h** change for certain ranges of **h** and fligt velocity **V** was observed while numerically analyzing. Thus, in some cases $\mathbf{Cd_{total}}$ turn out to be of a lesser value for a larger surface roughness value **h**, which might raise a doubt about an adequacy of the math model and validity of such result.

However, there is a quite explainable physical meaning (not an error!):

For fully Laminar flow and for relatively short models (in case under consideration - 2nd stage body's elongation λ **=10**) the base drag coefficient value is 2-3 times greater than the friction drag coefficient value (for velocities approaching critical value $\mathbf{V_{crit}}$ ($\mathbf{Re \approx Re_t}$)). This base drag ($\mathbf{Cd_{BS}}$) has a significant impact onto the total drag ($\mathbf{Cd_{total}}$). The turbulence occurrence at the very end (tail) of a model doesn't have a big impact yet onto a friction drag coefficient (for $\mathbf{X_t}$ values which are close to **1**), but already has a significant impact onto a decreasing of a pressure drag at the bottom ($\mathbf{Cd_{BS}}$).

Of course that doesn't speak in favor of optimal surface roughness searching and implementation of it onto a model. The math model might be slightly inaccurate IN THE PARAMETERS RATIOS (but not in a physical essentially).

However, this Paradoxial result might be the ground for the DESIGN and FABRICATION approaches and solutions combining:

- minimal friction drag at a minimum of Surface Rougness (see par. **«3.1.1. Minimal surface rougness and waviness»**) and;
- minimal Base Drag (see par. **«3.3. Base Drag Reduction»**).

The 2nd stage body's elongation has a specific value of λ **=10** (L =180 mm) in the cited above case.

However, I assume that results and conclusions for other λ values close to 10 (from the range of reasonable and being used on the models) should be close in their ATTRIBUTE-BASED and QUANTITY components to the results and conclusions presented above (for λ**=10**).

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1.3.4.3. Practical conclusions

1. Make the external surface as smooth as possible (with the lowest surface rougness) (see par. **«3.1.1. Minimal surface rougness and waviness »** and **«4.3. External surfaces lacquer coating»**).
2. Take into consideration the type of the dependence $\mathbf{Cd_{total}(V)}$ while selecting the engines parameters (burn time) for 2nd stages (see par. **«5.2. 2nd Stage Engine»**).

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1.3.5. Cd_{total} of 2^{nd} stage = f(v) for X_t = f(V). Impact of the body-NC juncture groove dimensions

As an example the results of numerical analysis of **Cd_{total}** of 2^{nd} stage vs. flight velocity **V** for critical Re value **Re_t = f(V)** (and correspondingly location of Laminar-to-Turbulent flow transition point **X_t (V)**) are presented.
2^{nd} stage with body's elongation λ =10 (stage’s length L = 180 mm) without tapered BT was considered.

Plot **$Cd_{total\ 2^{nd}\ Stage}$ = f(V)** for 3 values of groove dimension (h=50 μm, 100 μm and 200 μm) is presented.

Practical conclusions:
To avoid presence of grooves / notches on the external surface or make them minimal (see par. **«3.2. Absence of groove/chamfer at the body-NC juncture »**).

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1.3.6.1. NC-loading effect onto Cd_{total}. Static case

I have a feeling, that initial 2nd stage mass of about 15 g for given range of Cd_{total} (0.2 … 0.3) is not far from it’s optimal value, considering function Flight altitude H = f ($M_{2^{nd}\,Stage}$) (correct me if I am wrong). It also means, that increase of initial 2nd stage mass by 1…3 grams will not have negative impact onto flight altitude. Nevertheless, accurate flight altitude prediction will be required for … preliminary solution.

Yes, PRE-LI-MI-NA-RY. Because FINAL solution should come after flight testing – series of flight-testing.

However, let’s consider obtained results.

Loading of additional 2.5 g into the top of NC decreases Cd_{total} by 5% and 6.8% for Turbulent and Laminar flow correspondingly.

Remember the rule of a thumb, that:

$(\partial H / H) / (\partial Cd / Cd) \approx -0.6 \ldots -0.7$

In other words, it means that each 1 % in Cd_{total} drop corresponds to flight altitude increase of 0.6…0.7%.

And 5% of Cd_{total} decrease will result in at least additional 3% in flight altitude.

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1.3.6.2. NC-loading effect onto Cd_{total}. Dynamic effect

Besides, when you optimize mass of a 2nd stage it is necessary to take into consideration the following.

Usually, all existing methods / mathematical models and software for rocket model's flight altitude calculation consider a model as a point mass body, which moves translationally. And only few take into consideration a 2-dimentional motion - a shift as a result of a lateral wind/ sidegust.

What is a real motion of a model during flight?

A model makes also a rotational motion besides a translational motion.

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1.3.6.2. NC-loading effect onto Cd_{total}. Dynamic effect (Con’t 1)

Especially it affects a model motion:

- at impact of disturbances:
  - external disturbances (first of all – a lateral wind);
  - internal disturbances (including engine’s thrust vector oscillation)
- during rejection of these disturbances.

Certainly, if a model is statically unstable (CG of a model is below of CP), any deviation from a trajectory as a result of disturbance impact leads to even bigger deviation. As a result, this leads usually to a model’s destruction (in the air, or when landing).

In a case of a model’s static stability (CG of a model is above of CP) a model rejects disturbances.

At this a model’s turn (as a result of a disturbance –rejection) occurs not instantly, but with some delay / inertia.

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1.3.6.2. NC-loading effect onto Cd $_{total}$. Dynamic effect (Con’t 2)

The measure of this inertia (at the rotation) is the Moment of inertia $\mathbf{J_a}$ (with respect to a specific rotation axis), expressed as the sum of the products of the mass $\mathbf{m_i}$ of each particle in the body and the square of its perpendicular distance $\mathbf{r_i}$ from the axis **a** of rotation:

$J_a = \Sigma\, m_i \cdot r_i^2$

A model with an additional weight ∆M will have a larger value of longitudinal moment of inertia than an unloaded model.

Since a moment of inertia is defined as the product of the mass times the distance from the axis squared, that "square" will affect onto noticeable increase of a loaded model's Moment of Inertia, since a model is loaded into the nose – the most distant from CG point.

Flight altitude losses as a result of an arisen deviations are related not only and not just to trajectory deviation from vertical, but mainly to the fact, that during time when both disturbances and rejection of these disturbances is occurred, a model is flying at an angle-of-attack And this leads to a substantial increase of drag.

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1.3.6.2. NC-loading effect onto Cd $_{total}$. Dynamic effect (Con’t 3)

What is the impacts of disturbances and rejection of these disturbances into models flight for models with various values of the longitudinal moment of inertia?

1. On the one hand, the model without additional weighjt (i.e. with smaller value of the longitudinal moment of inertia) will deviate more (and quicker), than more inertial (loaded) model.
2. On the other hand, the model without loading will also quicker reject the arisen deviation.

What is a cumulative effect of disturbance-disturbance rejection onto integral / average value of drag coefficient for models with various values of the longitudinal moment of inertia (with and without additional weight)?

Usually models with a smaller value of the longitudinal moment of inertia have a smaller value of drag coefficient other things being equal.

The given approximate view of models flight trajectories with various J_y values under disturbance-disturbance rejection is rather conventional/conditional and depends on ratios of the longitudinal moment of inertia, disturbance’s magnitude and duration values and the nature of disturbance.

Certainly, it is possible to describe model's flight in details including a rotary motion. But it would be time consuming and very-very complicated – you had to solve not just differential equation of motion, but a system of equations (2, 3 or even 6, depending on accepted assumptions / simplifications).

However, there are no needs for a such complex analysis for a "fast" options comparison. Nevertheless, you had to take into consideration factors of a real flight.

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1.3.7. NC-top-rounding effect onto Cd total

An increase of Cd $_{NC}$ due to rounding of its top is greater than a decrease of fins Cd due to effect of the “Altimeter + Battery sliding forward”.

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1.4.1. Aft cone length / pitch cone angle (con’t)

Results of 6th WSMC-1985 (Bulgaria).

Our mini («Minakov's School») team: Ilyin-Mitiuriev designed a rear ejection model during preparation for WCh-85 in order to avoid NC-Cylinder juncture of the traditional front ejection design to have a Laminar flow on as-much-as-possible surface. The total length of the models was about 140-150 mm (including BT). I think it has been one of the shortest models ever presented at the WCh. However, the shortest does not mean the best!

There was a small, but a serious error in the design.

BT was shortening too much during the race-to-cut model's length.

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Results of 6th WSMC-1985 (Bulgaria) (con’t)

A short BT (or greater value of pitch cone angle) leads to air flow separation from the aft-cone surface and not at the point of back section, but at some place «up-the-stream». Consequently, back section pressure drag was related not to the back section area, but to the larger area corresponding to the point-of-separation.

Interestingly, our «shorty» screamed to us during the before-WCh-test flights that there is something wrong, unusual. In the first place, an ejection plume was visually slightly different during the launch of the models, but it was just a whisper. And in the second place, model’s BT was covered with a black coating at the length of about 2/3 from the base after each flight. The engines had a black delay, producing black plume. We did not pay much attention to it at that time.

However, there is a relatively simple explanation for this smoke:

- Airflow was not separated from BT at the very bottom, at the base point, but at the some point above it.
- This separation created a depression in the region along the BT surface between the base and the flow separation point.
- Delay plume partially headed into this depression region and colored the BT surface all the way-up-the-stream to the point of the separation.

It is very difficult to imagine simper and more accurate test/experiment to determine the critical (a flow separation) angle value. There was no special preparation needed for such experiment. The experiment and results came by random luck. And it wasn’t some special test-bench, but a flying model. The result was not affected by the impact of a measuring instrument(s).

The model was screaming “Look at me, stupid!” We did not hear it, and did not correct the model’s design – which would have required simply to increase the BT length in order to lower a pitch cone angle (or a local maximal tangent-to-centerline angle, for parabolic shape) to a value lower than critical.

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Recommendations for BT

1. In order to have a safety margin:

$\boldsymbol{\alpha}$ **con** $_{BT}$ **=** $\boldsymbol{\alpha}$ **max par** $_{BT}$ **= 7°**

Just for a reference: about 7° - bullets (manufactured at least by one company, which is one of the biggest ammunition producers in the US), have exactly 7°-BT. Yes, of course, the values of the similarity parameters are different for our models and for supersonic bullets: ballistic coefficient, M Number, Re Number. However, there are some similarities. These ammunition producers spent hundreds of thousands of dollars on their R&D to optimize a shape of the bullet(s). And yes, these bullets have a BT. At the same time IAW results, provided above (see par. **«1.3.1. Length of the 2nd stage»** and **«1.3.2. Length of 2nd stage BT»**) optimized S1 model should not have BT. Do bullets have some sort of the “3-to-1” regulations? … And yes, our optimal models will have BT without imposing the “3-to-1” regulations.

2. For Conical BT: Practically, the sharp edge of the Cylinder-Cone juncture has to be rounded considering:

- Stress-Strength issues;
- Airflow’s turn smoothing.

Just remember, it will increase BT length (the body length with a diameter < 40 mm).

I shared this story in such detail in order to bring up one more proof of the fundamental statement “THERE ARE NO TRIFLES IN THE SPACEMODELING!” Everything is important! You don’t need to work hard in order to discard a good idea for its application. Actually you had to work hard (and smart!) to avoid such a thing.

The same is correct for our hobby/sport parenting activity – the AEROSPACE INDUSTRY!

See the following slide with a ”lyrical digression” - a story-from-history.

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Let me share one very representative example form the history of the Soviet aerospace industry.

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“PROTON” rocket vs. Nut

Back in the 1960’s a rocket called “Proton” (by a general designer Vladimir CHELOMEI) was developed and tested.

There were several (at least 5) unsuccessful launches.

And all of them with the same outcome:

A takeoff; about 120 seconds of normal flight; and then… BOOM – an explosion almost at the same time during all flights – like a time-set-bomb.

All technician, engineers, managers were looking for reason(s) 24/7, digging through everything over and over. The government made statements that the company would have one last chance to make a successful flight, or else the entire Proton program would be closed.

Finally, one engineer had discovered a very simple error in a drawing of the fuel tank's assembly. Regular nuts (instead of self-locking ones) were specified for fastening of the fuel tank's internal parts.

And this is what happened during the flight: a vibration unfastened the nut(s), then a loose nut(s) fell into the fuel track, and when it reached the pump - a small piece of metal will crack a high-speed-rotating pump’s turbine every time – an explosion of the entire rocket. And since each nut was fastened IAW standard torque, it got unfastened during approximately the same time interval every time.

Later on the “Proton” rocket along with Korolev’s “Semiorka” (“seven” in Russian, a nick-name for the rocket design “Sputnik”, Gagarin’s “Vostok”, “Voskhod”, “Sojuz”, etc.) became (and to the present days) are the work horses for the Soviet Union/ Russia space programs, and for international space programs as well.

But the fate of this “work horse” was very questionable at the time. The “Proton” was almost killed by the simplest and the smallest part (what can be smaller and simpler? A washer?). Actually it wasn't a nut, but a human error. But such a SIMPLE ERROR! Like “The kingdom was lost, … because a shoe-horse nail was lost”. But in case with “Proton” there was no “butterfly effect” of consequential events, but the straight-forward impact of the nut on the entire rocket (and even on the program).

Conclusion: SEE ABOVE.

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1.4.2. Model’s total length (1st stage length) (con’t)

$\partial M0 / \partial L$ for 1st St body = 1.3 … 2.0 g/dm

The lesser value of 1.3 g corresponds to:

- Minimal specific weight per unit area of about 0.9 g/dm^2 - for 1st stage body (see par. **«4. Materials»**).
- Minimal specific weight per unit length of 2 g/m - for internal Flash Tube “1st stage engine to 2nd stage engine”, see par. **«8.1.1. Fabrication of a Flash Tube»**.

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2. Alignment

Observing flights of the S1 models during the Capital Cap –2011 (USA) and recorded launches of the S1 models during the European Championship-2011 (Romania), I noticed that a very few flights have a straight (and close to the vertical ones) stage separation, and especially a very few straight vertical 2nd stages flights without the spiral evolutions and wobbles. And it looks like the reasons for these non-perfections are misalignments.

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2.1. Fins plane - centerline alignment

A fin jig sketch with description (Fin Jig. Russian team standard. Alexey Korjapin's (Russia) design. Description and Drawings) was posted on the US-FAI-spacemodeling-group web site:
http://f1.grp.yahoofs.com/v1/wCHAThCm4_-B7Q81-5EIe9eBrwoZSzn6SXFO0AWGqcqw_60F6ZETa7Hvbb3cPEXOijOuwxymSu1xIgGHEB1YgksQsjBDjw_k/Techniques/Fin%20Jig_Russian%20Standard.pdf

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2.2. Thrust vector – centerline alignment (con’t)

- Pay attention to engine mount cyllidricity / variations in wall thickness (especially for short tubes).
- For extreme accuracy use special assembly mandrel(s).

The 1st stage body should have at least 2 parts in case of a BT presence.
I would recommend to make a cut (the 1st stage body juncture) neither at the point of a Cylinder-Transitional Cone juncture, nor at the point of a Cylinder-BT juncture, but somewhere above it (80 - 100 mm), just enough length for an alignment mandrel to have an alignment base.
The 1st stage body should have at least 2 parts in case of the BT presence.

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3.1. Body’s external surface

3.1.1. Minimal surface rougness and waviness

Attaining the minimal surface rougness in combination with minimal waviness is performed by sanding the external surface and attaining uniform thickness both along the generator line and radially.

It is essential for the best result concerning body's surface:

- To perform sanding on lather machine, centering a mandrel with body by tailstock center (for cylindrical part of the body).
- Change sandpaper gradually – from low grit (large abrasive grain sizes) to high grit (small abrasive grain sizes).
- Always use a lubricant (kerosene) while sanding a fiberglass surface, otherwise, while sending-dry:

a) Fiberglass dust resulting from the sanding penetrates everywhere, including your lung, which is harmful and even hazardous to health;

b) Sandpaper go duff very fast, cloging by dust ;

c) Formed buildups out of abrasive grain-fiberglass mix on the surface of sandpaper scratch the body's surface.

- Apply by turns the following two sanding methods:

a) OVER the SURFACE, pressing the sandpaper around the body’s surface, combining a rotational motion of a lathe with a translatory motion of a sandpaper;

b) ALONG the GENERATOR LINE, using for this purpose sanding block (a sandpaper on a flat plate). Something like a honing operation.

The microroughnesses (surface rougness) will be removed, but not the macroroughnesses (waviness) if only operation «a» (without «b») will be applied – Sandpaper (which is pressed around a body) will remove material from the surface eduidistantly following a existing waviness replicating it.

Level of waviness can be checked at the last stage of the sanding operations –optically (by eye). Attach a flat plate along the entire body's length, and place lighting (flashlight) on the opposite from an observer side of the body-mandrel. it is possible to differentiate by eye a gap of 1 micron from a gap of 2 microns with enough experience. A piece of mirror can be used as a flat plate. Requirements for a planeness of mirrors are higher than relevant requirements for regular plane glasses.

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3.1.1. Minimal surface rougness and waviness (con't)

2. Boby's surface should be degreased with benzine and acetone after sanding operations.
Apply a lacquer coating.
Fine grinding with high grit sandpaper, and polishing pastes gradually changing to polishing pasts with smaller abrasive grain sizes.
Follow the recommendations described above for sanding operations while polishing.
I recommend to coat a surface with a lacquer again if as a result of grinding/polishing somewhere on a surface the lacquer coat was removed.
Otherwise, the epoxy component of epoxy-fiberglass (which is softer than fiberglass) will be removed deeper than harder fiberglass component during grinding / polishing.
Thereby the cellular structure will surface. That will cause an additional turbulence, and all the more - the asymmetrical turbulence about model axis. Any asymmetry in a flow will translate into the additional losses due to occurrence of an angle of attack.
It is clear that the lower surface roughness require more labor effort.
There is a rule of a thumb in mechanical engineering for metal parts fabrication:
A reduction of part's surface roughness in half translates into a double labor costs of a part.
I assume that for our plastic models/parts this ratio is less than double, but the general tendency exist also.
Let's assume that reduction of surface roughness in half results into labor cost increase by just 10%.
Then, for example, a roughness reduction by first increment of **10 μm** from **h= 20.5 μm** to **h= 10.5 μm** results into processing time increase by 10%. But, the next roughness reduction increment of **10 μm** (from **h= 10.5 μm** to **h= 0.5 μm)** results into processing time (labor cost) increase by 50% (!).

But at the same time the effect from the second reduction of a roughness is less than from the first one in terms of additional meters of flight altitude (see slide **«1.3.4.2. Results review (con't 4)»** of par. **«1.3.4. Cd_{total} of 2^{nd} stage = f(v) for X_t = f(V). Impact of a surface roughness»**).
There is an effect of a saturation of final result increase.
However, this effect is a distinctive example of a certain philosophy of success. Moreover, that applies not only to modelling/sport (of caurse, under conditions of tight results where top competitors are “neck and neck”).

You had to make disproportionally more efforts for an equal increase of tomorrow's result in comparison with:
- your own yesterday's increase of result or/and;
- results of other competitors.

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3.2. Base Drag Reduction

3.2.1. Turbulization of the air flow at the bottom of a body

There is a difference between Laminar and Turbulent flows near body's Back Section..

In a case of Turbulent flow due to a simple vortexity / circulation in a boundary layer a small part of a flow gets under the very edge of the BS. Therefor, there is a lesser depressurization (or higher pressure) behind the body's BS.

Certainly, pressure behind the body's BS is uneven along the radius of the section and has some distribution in values. However, increase of pressure in some part leads to increase of BS average pressure, which defines the value of the Body’s BS drag coefficient.

Therefore, it will be a good idea to turbulize intentionally a flow at the model’s bottom area (if it is still remains Laminar) by inserting some element which will destabilize a flow (groove / bulge / collar).

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3.2.2. Air flow injection into the body's base region

BS pressure will increase (i.e. BS drag will be reduced) if to bypass part of the airflow into a BS region.

This can be done by the following design approaches:
- Slots for air flow in the body’s bottom;
- Or to go further, to make an air ducting (injector) which is more difficult to fabricate. But this option will be more efficient (smaller pressure – friction losses on a flow passing through).

Certainly, these options will bring some losses mainly connected with the increased wetted body’s area, and therefore the increased friction. Besides, turn of a flow (part of it) will result in additional pressure drag.

Additionally, it is necessary to take into consideration that if slots (or air inlets) are made between fins, it will lead to a pressure overflowing between fins surfaces. That will lead to a reduction of their efficiency and therefore that will require increasing of fins area.

However, I think, that overall total drag value can be reduced with appropriate design, considering large portion of the BS drag value in the total drag value.

Roughly, in case of an air ducting channel - injector we have BT hidden under external body’s line. But after all the FAI Code doesn’t say anything about model’s internal design.

The only one little thing is remaining – to make a design with pressure-friction losses (of airflow through internal ducting channel) lesser than reduction in BS drag value.

Quite probably, channel’s cross-section area along its length should be constant in value (or should be constantly increased) for avoidance of an additional pressure losses in a flow passing through internal channel.

Together with requirements for channels symmetry will require special care for their fabrication (probably using matrix technology) and high coaxiality for assembling. Most likely, you had to use CNC machining to fabricate matrixes / jigs to make parts and for assembling such a ducting channel-injector.

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3.3. Fins

Flat fins, as thin as possible (with rounded leading edge and sharp trailing edge), with thickness of 0.25 - 0.30-mm made out of carbon (carbon-epoxy) is a good option. But it isn't the best.

The better option is fins with biconvex profile.

The advantages of such fins vs. thin flat fins:
- Fins with biconvex profile have a smaller profile drag values;
- Fins with biconvex profile have higher value of normal force coefficient curve slope ($\partial C_N/\partial \alpha$). This means that fins with a smaller area will provide the same stability margin. That lead to reduction of drag friction.
How much this may reduce fins area?
It should be determine by you.

Of cause, manufacturing of such fins and their assembling into model’s body will require some additional efforts. It is much easier to glue flat fins into body than airfoiled non-flat fins, which will require some special matching plate for fin jig.

However, But it shouldn't take fantastic efforts for a matrix fabrication, using today's technologies and CNC machining. It will be worthy of it. Besides, it is for you to decide.

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3.3. Fins (con’t 1)

Biconvex profile

The following should be taken into consideration:

1. Maximum thickness point

The line of maximum thickness should be located in about a 1/4 -1/3 of the local chord length from Leading edge. Approximately on a fin’s chord. Moreover, value of relative Maximum thickness point (**a/b**) should remain constant in magnitude along the fin’s span.

2. Leading and Trailing edges

- The Leading edge can be rounded with a small radius.
- From a point of view of minimum profile drag value the Trailing edge should be sharp. However, factors of rigidity, strength and non-fragility during handling and landing lead to thickening / rounding the Trailing edge as well. A small thickening / rounding with a small radius shouldn't worsen the profile characteristics considerably.

3. Fin’s relative thickness

Considering rigidity, strength and aerodynamics parameters, fins are made with a variable chord length along the fin’s span (elliptic or trapezoidal shape). In order to keep the values of profile’s relative thickness along the fin’s span constant, the thickness along the line of the maximum thickness should decrease proportionally with chord reduction. Otherwise local normal force coefficient curve slope $(\partial C_N/\partial\alpha)_i$ will have various values, since $(\partial C_N/\partial\alpha)$ depend on relative thickness $\underline{c}$=c/b. Non-uniformity in $(\partial C_N/\partial\alpha)_i$ will negatively affects an overall flow and will lead to a flow migration.

In order to meet requirement:

$(\partial C_N / \partial\alpha)_I = const$ along the fin’s span.

It is necessary to provide:

$c_i/b_i=const$

If, of course, not to consider the effect described below (see the next slide).

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3.3. Fins (con’t 2)

4. Dependence of normal force coefficient curve slope on Reynolds number

Normal force coefficient curve slope value ($\partial C_N/\partial \alpha$) depends on Reynolds number, the greater Re number the greater ($\partial C_N/\partial \alpha$) value.
This means that fins with a variable chord length have actually non-equal values of local ($\partial C_N/\partial \alpha$) for different cross-sections along the fin’s span in defiance of c_i/b_i equality.

However, it is possible to compensate (to some degree) the effect of ($\partial C_N/\partial \alpha$) dependence on Reynolds number by slightly changing relative thickness for the most “defining” range of flight velocity, since dependence of ($\partial C_N/\partial \alpha$) from Re and from relative thickness **c** aren't linear.
Mentioned effect is rather "thin", and its impact is not substantial. However, if you want to consider it and to apply into your model’s (fin’s) design, you should do it carefully after conducting a corresponding numerical analysis.

Besides, as well as for solving any other optimizing problems of rather low level it is necessary to consider:
- other aspects (which at this level weren't taken for consideration after decomposition of the GENERAL problem);,
- how the “optimal” option determined for lower level will affect other parameters?

Slide 88

4.1. Paper vs. epoxy-fiberglass

Strength-to-weight ratio

Paper has a lower strength-to-weight ratio.

The lightest paper you can use is probably regular printing paper with thickness of $\delta = 0.1$ mm and a specific density per unit area = 0.75 g/dm^2. I doubt that model’s body parts can be made out this paper in one layer without some protective coating, which will increase weight. Two layers of paper (even without protective coating) are heavier than fiberglass-epoxy.

The weight of 0.9 … 1.0 g/dm^2 is achievable using fiberglass-epoxy material. I did it 20 years ago, and assuming that the technology has moved forward, this result can be improved using fiberglass-epoxy (at the largest area of a model, the cylindrical part of the 1st stage) with the wall thickness of 0.06…0.07 mm.

Resistance to moisture

Moisture substantially decreases paper’s property. Not only rain, but also a high humidity has a negative impact on the paper’s strength. Parts made out of a paper can’t be reliable, especially fitting parts / surfaces (engine’s mounts, the fitting cylinder on top of the 1st stage).

Ring frames for engine mount can be made out of balsa and / or fiberglass-epoxy.

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4.2. Wall thickness of fiberglass-epoxy parts

OD of all the parts is measured with a micrometer during mechanical finishing, except for the OD on the conical surfaces. The final condition for these surfaces is determine by indirect indicators such as:

- Surface smoothness
- Intensity of coloration.

The areas of these parts are relatively small, an extra micron or 2 on the wall thickness will not increase the weight noticeably. But it is very easy to make a hole on these relatively thin surfaces (2 layers of 0.025 mm of a fiberglass with epoxy).

Slide 90

4.3. External surfaces lacquer coating

A. 1st Stage

I do not believe that laminar flow can be sustained on a 1st stage cylindrical surface (the largest area of the model) after passing the harsh condition of a Transitional Cone between cylinders of the 2nd and the 1st stages even at low velocities (i.e. low Re numbers) of the 1st stage (V average ~ 40 m/sec). Therefore, it makes no sense to make the 1st stage surface of a lower roughness, than can be achieved with just sanding it without a lacquer coating / polishing. Do not waste your time, and do not increase a 1st stage weight.

B. 2nd Stage

The external body surface should be lacquer coated and polished. For the technique see par. **«3.1.1. Minimal surface rougness and waviness»**

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5.1. 1st Stage Engine

The 1st Stage Engines, used with a piston, have to be designed / or selected among the existing ones not only to be light (as a general rule) but to get the most out of a given total impulse in both phases of its work – on a piston and at the rocket-jet phase.
Actually an engine working with a piston can be considered as a 2-phase engine:
the 1st phase – the Internal-Combustion Engine
the 2nd phase - the Rocket Engine itself.

The goal of the piston is to utilize the very ineffective exhaust gases of a rocket engine at take-off, which in its turn has the most efficiency (a propulsion efficiency) when a velocity of the rocket equal to a velocity of the exhaust gases. And at the very beginning of a rocket flight during take-off (when a rocket’s velocity close to "0") all these gases are literally blown to the wind. The purpose of a piston is to contain and utilize internal energy of these hot high-enthalpy gases. A coefficient of the efficiency of the most advanced Internal-Combustion Engines is about 45%, and if we are able to utilize even 1/10 of it, we will be in gain using our pistons.

5.1.1. Engines Thrust diagram / burn time

The purpose of the 1st stage is to get as much speed as possible of course, additional altitude will be good as well. However, consider the fact that the 1st stage burnout velocity is relatively low (to the exhaust gases velocity of ~ 900 m/s (black powder) to ~1200 m/s (compounds)), ~ 70 m/s, and the average velocity (during the 1st stage flight) even lower (~ 40 m/s), will it be more rational to burn the 1st stage engine as much as possible on a piston?
This will lead us to:
A. “Faster“ engines (with a shorter burn time). But it also means a heavier engine due to the increased engine's wall thickness (an internal pressure increased due to the increased fuel burning surface area and/or the increased engine’s ID and OD).
B. Stronger and heavier model (1st stage) to sustain high level of the acceleration at the separation point from the piston - actually to sustain a suddenly applied load of the 2nd stage weight, which is for mass of 15 g will become 1.5 kg (for acceleration level (for example) at 100G). And do not forget to multiply that 1.5 kg by a factor of 2 to consider a dynamic load factor of a suddenly applied load.
The approach for the 1st stage design might be some different, than the one described above.
Additional R&D is required to get the answer.

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5.1.2. BP engines vs. compound engines

It is possible that BP engines for the 1st stage are more efficient than engines with greater specific impulse for the 1st stage (or the BP engines are as good as the compound engines), since the more gases (gases’ mass) are produced for a piston, the greater pressure and entire effect of it.
- BP engines have more fuel to burn.
- But then engines with a greater specific impulse have greater exhaust gases temperatures.

Additional R&D is required.

Slide 94

5.1.3. Prevention of a Total Impuls loss for 1st stage engine

Usually 1st stage engines for multystage models have no delay.

Not all of engine's combustion product will exhaust through a nozzle at the end of engine burning If no measures will be taken in order to cover an «open» surface of engine's solid grain. Beyond that the effect of «Reverse Thrust» might occur.

5.1.3.1. Decrease of a total impuls as a result of breakage of engine's solid grain top part

During propellant burning and shifting up of a burning front inside of a grain chamber (GC) and burning front's reaching of the very top layers of a solid grain, the very top part of this solid grain will break-up under a relatively high pressure (approximately 5 atm (or 0.5 MPa)) inside of GC. This top layers of a solid grain have function of Top End for Grain Chamber. The wall thickness of this Top End will shrink, and at some point of a burning will reach a critical value and break-up (before it burn-out completely). Pieces of this «Top End» (not burned-out yet pieces of propellant) which are formed at the breakage point, will burn inside of the GC of increased volume ($\mathbf{V_{GC\ 2}}$).

Along with that this GC will have not just one outlet (a nozzle), but also - an open engine's top end.

Pressure value inside of GS ($\mathbf{p_{GC}}$) will fall due to increace of GC's volume. That automatically leads to reduction of an exhaust gas velocity $\mathbf{V_{ex}}$ (i.e. specific impuls $\mathbf{I_{sp}}$), which means reduction of a total impuls $\mathbf{I_{\Sigma}}$.

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5.1.3.2. Decrease of a Total Impuls as a result of 2nd outlet forming

The top exhaust outlet for 1st stage engine, enclosed into a model's structure, usually is the internal enclosure of a Flash Tube.

A hydraulic resistance / pressure loss $\mathbf{\Delta p_m}$ for transition: large diameter (GC) – small diameter (Flash Tube) for passing of exhaust gases $\mathbf{\Delta p_m}$ (GC- Flash Tube) is less than $\mathbf{\Delta p_m}$ (GC-Nozzle) (about 10% less). because the Flash Tube cross-section area (for $\varnothing\mathbf{D_2} \approx 3$ mm) is several times less than Nozzle cross-section area (for $\varnothing\mathbf{D_1} \approx 1.6$ mm).

Exhaust product of remaining solid grain will mostly exhausts up (through a Flash Tube).

Thus the total mass of a propellant $\mathbf{m_{p\Sigma}}$ which exhausts through a Nozzle will decrease and therefore the total impuls $\mathbf{I_{\Sigma}}$ will decrease too.

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5.1.3.3. Reverse thrust

Besides, the part of combustion product which exhausts through Flash Tube will create thrust in opposite direction (Reverse Thrust).

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5.1.3.4. Forming a Top End for Grain Chamber

Ussually a top surface of solid grain is covered up in order to prevent negative impacts mentioned above – to form a Top End for Grain Chamber:

1. By applying epoxy or,
2. By incerting a carton washer and applying epoxy along juncture “cylindrical surface-washer”.

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5.1.4. Delay time for the 1st stage engine

There is a question: should the 1st stage engine have a delay, $\tau_{delay} > 0$ (between the end of the 1st stage engine burning and the 2nd stage engine firing) in order to have a greater performance for model – higher flight altitude?
I assume, that a stages separation is simultaneous with 2nd stage engine firing.
I don't think it is possible to separate stages before 2nd stage engine firing without substantial increase of the 1st stage mass and/or without a decrease of reliability.

Slide 99

5.1.4.1. External ballistic

Yes, time of a 1st stage's coastal flight is increasing (from zero for a version with $\boldsymbol{\tau_{delay}} = 0$) with $\boldsymbol{\tau_{delay}} > 0$. Thus a total flight altitude of a 1st stage is increasing as well.
However, the initial flight velocity of the 2nd stage $\mathbf{V_{02}}$ is decreasing as a result of model's aerodynamic deceleration during this delay time τ_{delay}. Thus a total flight altitude of a 2nd stage is decreasing. And the fall of this velocity $\mathbf{V_{02}}$ is so intense, that model's total flight altitude is decreasing despite of the increase of a 1st stage flight altitude.
Basically, altitude augmentation obtained during delay time will be “eaten” by disadvantage of reduced initial flight velocity of a 2nd stage.
I believe you can prove me right (or wrong) by “playing” numerically, using software for flight altitude prediction.

Slide 100

5.1.4.1.1. Decrease of air density (ρ) during flight

Then there is a question, why it is some real rockets have a delay between stages separation and the 2nd stage engine firing? For example, US missiles «Pershing-2» had delay for ignition of a 2nd stage engine. And this daley have been used for the same specific reason – to reduce an aerodinamic velocity loss.
But there are some differences between models and real rockets:

1. Level of air density decrease during flight.
2. Values of Ballistic Coefficients.

Delay in ignition of 2nd stage engines for these “Pershing-2” missiles was done in order to pass through a lower atmosphere of high density and not to lose big on aerodynamic drag (which is proportional to the square of the velocity) – to pass through this dense atmosphere with lower velocity.
But in our case of S1 models with substantially lower flight altitudes – our models can not pass these dense layers of atmosphere, remaining within those all the time - even within the range of 500 meters the air density is reduced at about 6 %. The air density reduction within the range of 50-100 meters (flight altitude range of the 1st stages for S1B models) is about 0.5–1 % respectively.
There is no effect of air density decrease (attributable to flights of real rockets) during flights of S1 models.

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5.1.4.1.2. Ballistic Coefficient (BC)

BC = (2 · m) / (Cd · A),

where:

m – mass of a body (rocket), kg;
Cd – aerodinamic drag coefficient;
A – reference area, m^2

Ballistic Coefficient (BC) of a body is a measure of its ability to overcome air resistance in flight.

The Values of Ballistic Coefficients for our models are significantly lower in comparison with Values of Ballistic Coefficients for real rockets – 300 (!) times lower than for «Pershing-2» missiles. Thus, there is no similarity between 2 cases.

Both less inertial and less dense S1 models are rather «cotton balls» than «rocks» (which is more appropriate comparison for more dense real rockets). Thus, S1 models will lose the velosity very fast during coastal flight (delay time on the 1st stage engine).

Besides that the decrease of the flight velocity during coastal flight before stages separation could have negative impact onto flight trajectory – a deviation from a vertical flight in case of strong enough wind, which is not a rare thing during competitions.

There is no need to have a delay on the 1st stage engine (as far as external ballistic is concern).

Slide 102

5.1.4.2. Internal ballistic

Solid Grain burning inside of a Grain Chamber (GC)

Let's consider the internal ballistics of the engine, specifically solid propellant burning inside of a Grain Chamber (GC) / Combustion Chamber.

After engine's firing the burning front recedes inside of the Solid Grain in a direction perpendicular to the burning surface with somewhat equal rate along all burning surface (practically equal, assuming the equality of the internal parameters of the GC). Therefore the burning front recedes equidistantly.

That also means the burning front at the top of GC is not flat but rather of a spheric shape (or similar) – with the most forwarded point of the burning front located on the engine's symmetry axis. Consequently this burning front will reach first the top flat surface of the Solid Grain in the center of it where the hole in the washer is usually located.

Then the black powder charge (for firing the 2nd stage engine) will ignite and burn, and generated hot gases will reach Solid Grain surface of the 2nd stage engine and will fire it before than burning of the 1st stage engine's propellant will be completed (in the ring segment enclosed between the central axis, the engin's interna wall, the burning front and the engin's flat end).

Slide 103

5.1.4.2.1. Burning rate and burning front shape of a Solid Grain during the phase of the internal-channel burning

At the initial phase of the Model Rocket Engine (MRE) operation the internal-channel burning (basically receding horizontally) takes place alongside with end burning (or cigarette-burning) upwards (in a vertical direction). Internal processes during this phase of burning are more complex than the burning process during just the end burning, which takes place at the end of MRE operation.

That is due to the fact that the propellant burning takes place with combustion gases flowing parallel to the burning surface. Plus the Grain Chamber internal ballistic parameters are varying also along the burning surface.

Presented above schematic of Solid Grain burning inside of a Grain Chamber, namely the equidistant burning-front advancing assumes the equality of the Burning rate along all burning surface.

However, in reality this is not totally true.

Propellant burning rate (and therefore the burning front shape and non-uniform burning which alters this shape) is influenced by certain factors.

This impact factors include (but not limited to):

1. Local combustion gas velocity parallel to the burning surface.
2. Internal ballistic parameters of the combustion gas (first and foremost – the pressure) on the burning surface.

Slide 104

5.1.4.2.2. Local combustion gas velocity on the burning surface. Erosive burning

Examining the burning processes inside of the Grain Chamber, several distinctive zones can be conditionally distinguished, shown on the Schematic of the propellant burning and presented on the slide.

2 fragments of burning surface are shown for the comparison of the changes in the burning zone:

(1) – top part of the channel;
(2) – lower part along the channel, closer to the nozzle.

Slide 105

5.1.4.2.2. Local combustion gas velocity on the burning surface. Erosive burning (con’t 1)

The Combustion product generated during propellant burning are accelerated and moved down in the direction of the nozzle.

Combustion gases flowing the burning surface have some impact onto the burning process itself.

Specifically, Combustion Gas flow velocity is increasing down the flow.

Upon The Gas flow velocity increasing, the turbulent core of the Combustion gas flow shift into the Chemical reactions zone and Gasification zone.

As a result of that the Turbulization of the burning zone and its approaching to the surface of the solid propellant take place. That leads to heat and mass transfer enhancement.

Intense heat input into burning surface and more intensive mixing of Gaseous components induced by the turbulence of the flow enhance chemical reactions, which lead to the increase of the propellant's burning rate.

This augmentation of burning rate is referred to as **Erosive Burning** (*).

*) – It is interesting that the term “Erosive Burning” is somewhat confusing since the phenomenon of burning rate augmentation caused by heat factor but not by erosive factor. However, today this term is generally accepted on “both sides of the ocean” and also in both technical English and Russian.

Profiles of Gas flow velocity, Local pressure and Burning rate (presented on the slides) reflect rather a qualitative figures (being exaggerated).

These profiles are conditional since values of Gas flow velocity and Local pressure are different on engine's axis and near the burning surface and those values have profiles (distributions) in each horizontal cross-section.

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5.1.4.2.2. Local combustion gas velocity on the burning surface. Erosive burning (con’t 2)

For many propellants, a threshold flow velocity ($\mathbf{V_{th}}$) exists (or threshold mass flux velocity ($\mathbf{(\rho \cdot V)_{th}}$)). Below this flow level, either no augmentation occurs, or a decrease in burning rate is experienced (negative erosive burning).

Value of threshold flow velocity varying with propellant type and chamber pressure. For most propellants the value of $\mathbf{V_{th}}$ does not exceed 200 m/sec.

However, it is more reasonable to use threshold mass flux velocity $\mathbf{((\rho \cdot V)_{th})}$ (where ρ - density of Combustion gas in a flow) than threshold flow velocity ($\mathbf{V_{th}}$), since intensity of convection heat transfer depends particularly on mass flux velocity.

I assume, that both $\mathbf{V_{gas}}$, and $\mathbf{(\rho_{gas} . V_{gas})}$ values for small enough model rocket engines (in addition to a small level of their internal pressure during burning, and therefore small values of combustion gas densities ρ_{gas}) - in comparison with real rockets – will not exceed (or will not exceed greatly) corresponding threshold values. Consequently even if the Erosive burning will take place, it will not be intensive enough to affect burning rate non-uniformity.

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5.1.4.2.3. Local pressure of combustion gas on the burning surface

2 fragments of burning surface are shown for the comparison of the changes in the burning zone:

(1) – top part of the channel;
(2) – lower part along the channel, closer to the nozzle.

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5.1.4.2.3. Local pressure of combustion gas on the burning surface (con't)

In an operating rocket engine, there is a pressure drop along the axis of the grain chamber, a drop that is physically necessary to accelerate the increasing mass flow of combustion products toward the nozzle. The static pressure is greatest where gas flow is zero, that is, at the front of the engine.

Certainly, values of local pressure are varying across each horizontal cross-section of the burning Grain Chamber. However, as some researches have been showing, the pressure in horizontal cross-sections are practically does not varying and shape of its profiles are close to rectangular.

For most propellants burning rate V_{burn} is dependent upon the local pressure in accordance with power-law, increasing with pressure growth:

$V_{burn} = f(p) = k \cdot p^n$, where $n > 0$

It is caused by the increase of intensity of the heat transfer to a propellant surface with increasing pressure. With that the rate of chemical reactions with gaseous substances generation in the Solid phase increases. At the same time the increase of the gaseous reactants concentration leads to increase of the rate of exothermic reactions in the Gaseous phase. The high-temperature Luminous flame zone shifts towards a Solid propellant surface due to decreasing of Gasification zone thickness.

Decreasing pressure has a reverse impact onto burning process.

Thus, the burning rate of the propellant will fall along a surface of the channel toward the nozzle due to pressure drop in this direction. That means the burning front will move faster at the top than below along the channel (in a horizontal direction). Consequently it will increase the Convexity of the burning front shape.

Thus, the impact of non-uniformity of pressure distribution along the burning surface of a grain chamber is opposite to the impact of the erosive burning.

However, impacts of both mentioned factors on burning rate are rather insignificant. And sometimes these factors are not considered even for real rockets, especially due to these factors offset by their counter-effect.

Nevertheless, these factors are mentioned in the given material:

- To expand the perception about the complexity of such a simple devices as MRE, having described (though far from completion) the internal physics of model engines operation;
-And … paradox … are mentioned that, these factors, could be not considered. But consciously and reasonably!

Slide 109

5.1.4.2.4. Internal ballistic and stages separation

The burning rate of a Solid Grain is about $\mathbf{V_{burn}} \approx 1$ cm/sec
Hot combustion gases expansion rate inside of the flash tube is (as I assume) about $\mathbf{V_{gas}} \approx 50$ - 100 m/sec.
So, even a big difference in a distance:
- The order of several millimeters (or just 1 mm) – for the burning out completely the remaining propellant;
- 200-300 mm (the length of the flash tube) - for hot combustion gases expension along the flash tube

is not the essential factor for any noticeable delay in the ignition of the 2nd stage engine.
Due to this reason the 2nd stage engine firing and the stages separation occur before the completion of the 1st stage engine operation. And the remaining propellant of the 1st stage engine will burn and generate combustion gases which will exhaust through the nozzle as well as through the hole in a washer – and then through flash tube. And practically engines of both stages will be firing at the moment of stages separation and shortly after that.
Consequently the total impulse of the 1st stage engine will not be fully utilized.
Besides, most likely the propellant next to the engine's wall area will burn faster than the propellant at the rest of the horizontal cross-section for the similar reason specified further, regarding the delay charge of the 2nd stage engine (see par. **«5.3.1. Delay increase by 0.3 - 0.5 sec»**) – specifically, that the propellant's burning rate is somewhat inversely related to the propellant's density. When the Solid Grain is formed, the very-near-wall region of the propellant does not have the same pressure from a pressing instrument. Because of that, the density of the propellant in this near-the wall region is lesser than the density of the propellant at the rest of the Solid Grain's cross-section).

These 2 mentioned above factors – equality of the burning rate and nonconformity of propellant density (along with Erosive Burning and Combustion Gases Pressure Nonuniformity) are defying the burning front shape. Moreover, the lesser density of the propellant near-the wall region slightly smooths the burning front shape and reduces the convexity of it.

I assume, that a simple enough test-experiment of ground-firing with 1st stage holding and with high speed camera/photo-shooting could be conducted for the partial proof of such hypothesis /assumption about nonflatness of burning front inside of a GC and Convexity of its shape.

* - Photo of stages separation of PEREVEROV's Mikhail (Russia) scale model Ariane-3 V10, category S7, WSMC-2012 (courtesy of Vladimir Sedov (Russia)) is symbolic, but to some degree gives illustration of the above-said (in spite of there are more than one engine on the 1st stage and more likely ignition of 2nd stage engine / stages separation made from one of the 1st stage engines or from electronic device).

Slide 110

5.1.4.3. Prevention of a Total Impuls loss for 1st stage engine

I Suggest two possible solutions for the prevention of the Total Impuls loss for 1st stage engine:
1. To shift the hole in a washer (which cover propellant on the top) from the center closer to engine's wall.
As it turned out during preparation of this material, such a method was used by some modeler(s) from former republics of Soviet Union.
2. To make a small delay engine $\tau_{\mathbf{delay}}$ = 0.3-0.5 sec for 1st stage engine.
It, certainly, will increase the aerodynamics losses (mentioned above in par. «**5.1.4.1. External Ballistic**»). However, I assume, it will be compensated with usury by utilization in full of the 1st stage engine's total impulse.
I assume that the second suggestion is more preferential despite the disadvantage of the decelaration during 1st stage costal flight, considering that in reality the burning front could be nonsymmetrical due to nonhomogeneous dispersion of the propellant's properties over volume of the solid grain.
As it turned out during preparation of this material, such a method is in use by Ukranian modelers under the guidance of Igor VOLKANOV (Ukraine).

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5.2. 2nd Stage Engine

For reference:
Jiri TABORSKY himself is:
- The 1st ever world champion in S1 category, 2nd WCh-1974, Czechoslovakia, where S1 event was included the first time into the world championship program.
- Holder of the total 3 individual world titles.

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5.2. 2nd Stage Engine (con't 3)

A/d drag **D = k · Cd · V^2**

1. A/d drag **D** increases substantially with **V** (due to **V^2**).

2. In general, for a subsonic flow, **Cd** decreases with **V** (since a Friction Drag is a big part of the total Drag and the friction drag coefficient decreases with **Re** Number (i.e. with **V**)).

However, at some point with V_{flight} increasing, airflow from fully laminar transfers into a partially laminar /partially turbulent. And that will increase **Cd** with **V**.
(see above par. **«1.3.4. Cd_{total} of 2nd stage = f(v) for X_t = f(V). Impact of a surface roughness»**).
And what IF, this jump in flow takes place in the case of "fast" engine, and at the same time will not take place in the case of "longer-burning" engine? Along with the first factor that will support the idea of an engine with the greater burn time.

Optimal t_{burn} - ? An additional R&D is required to get the answer.

Slide 115

5.3. Delay time increase (2^{nd} Stage Engine)

A working experience with the engines (especially with not very high quality engines) taught us, the modelers of the Soviet Union / Russia, some techniques in order to make these engines perform as they should to perform, to make them more reliable. Quiet opposite how, for example, US modelers handle their engines. I do understand that US modelers follow the rules, the safety code – do not touch engines at all. This sounds to me, personally, quiet strange. Not that they follow the rules, but that the rules limit them to the point where they can’t even remove/add /change an ejection charge. What about the issue of changing delay time? Forget about it! It is a heresy.

I do understand that is about responsibility and reliability.

For exactly the same reason(s) - safety / reliability, modelers in the Soviet Union / Russia HAD TO work with the engines.

Sometimes a delay has not been in a shape of a tablet, pressed on the top of a fuel charge, but pressed along an internal cylindrical surface (pressed in the gap between a pressing puncheon and an engine’s wall). There were even a few “funny-made” engines: “nozzle - BP charge – delay charge - BP charge – delay” and “nozzle - BP charge - nozzle clay charge – delay”, etc.

The experience to deal with the sometimes-bad-quality-engines gave us some knowledge and taught us some techniques.

Sometimes an engine’s delay is quiet of the optimal delay time. And it would be a good idea to correct this delay time. It is very easy to decrease delay time: by just simply removing (proportionally) a delay from an engine.

To increase the delay time will require more effort. However, it is not complicated.

5.3.1. A delay increase by 0.3 - 0.5 sec

This is even simpler than to remove a delay.

- Remove an ejection charge.
- Insert a carton washer (with a central hole ∅ ~3 mm)
- Put epoxy along the juncture “cylindrical surface-washer”.

Engines treated IAW such techniques will have an additional 0.3 … 0.5 sec of a delay time on base of 4…6 sec of a delay time. Sounds like magic? Not at all.

Delay density is not the same near the engine’s wall compare to the center.

When the delay is formed, the very-near-wall region of the delay powder does not have the same pressure from a pressing instrument. Because of that, the density of the delay in this near-the wall region is less than the density of the delay at the rest of the surface.

The delay's burning rate is somewhat inversely related to the delay's density.

Consequently, the delay’s burning front is not flat, but the delay from the near-wall region is burning slightly faster. And the total delay time is defined by a burning time in this region. By blocking this region with washer and epoxy we will have a slightly longer delay time.

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5.3.2. Delay increases by more than 0.5 sec

This will require more than just the above-described “magic”.

1. Insert a balsa washer inside the engine on the top of the delay and glue it with epoxy.

2. Put an additional delay powder inside a washer hole. Press this powder in with a steel rod by hand. Do not strike.
A small surface area provides sufficient pressure and results in small delay-powder consumption.

An additional delay's height is checked with a slide gauge.
A delay’s burning rate is sufficiently constant – about 1.0 - 1.5 mm/sec.
An important issue is the type of a delay powder. Some types of delay do not have a reliable result.
However, the type we were using (Koriapin Alexey, Ilyin Sergei, Kuzmin Victor, Mitiuriev Alexander, …) gave us the absolutely failproof result in regards to ejection charge lighting and a burning rate consistency.

Removing a traditional delay from an engine and replacing it with an electronic device will visibly improve the model’s performance.

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5.4.2. Delay’s “parasitic” Total Impulse (*)

* - Applied In case if engine thrust stand measures the delay thrust

A traditional delay produces low levels of thrust during the coast part of the trajectory, and therefore, the total Impulse of a delay is a part of the Engine’s Total Impulse.
The specific Impulse of this “delay’s thrust” is very low and therefore, this delay’s thrust is not effective. It takes away a small but an effective part out of the Total Impulse of the engine’s cruise mode (with a high Specific Impulse value).
Replacing a traditional delay with an electronic one will remove this “parasitic” Total Impulse and will allow an increase of the engine’s propellant mass / effective Total Impulse.

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5.4.3. Delay and model’s ballistic coefficient

Lost weight (of about 0.8 g or ~ 5% of a total coastal weight) during a coastal flight, leads to the coastal flight altitude decrease. The total altitude loss is at least 1 %.

The rocket (2nd stage) loses about 80 - 90% of delay’s initial mass during its coastal flight. The rest (20 - 10%) stays on-board in the form of slag.
Heavier rocket with the same burnout velocity will fly higher than a lighter one. Losing weight (even if it is just about 0.8 g loss, or 5% of a coastal weight loss / value of the ballistic coefficient loss) will decrease the coastal flight altitude. The altitude loss is at least 6 meters on a base of 600 m.

Removing weight-losing traditional delays will increase the total altitude by at least 1%.

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6.1. Some Physics and Math behind a Piston

Let’s consider some physics / math of a piston. And let’s use the fundamental principals and laws without viewing details of the relatively complex thermodynamic processes, numerical simulations, etc.

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6.1. Some Physics and Math behind a Piston (con’t 1)

Model’s velocity at the end of t = 0.1 sec IAW Tsyolkovsky’s second Problem:

V(t=0.1 sec) = - 919 m/sec · ln ((30 – 0.2) / 30) – 9.81 m/sec^2 · 0.1 =
= 6.4 m/sec – 1 m/sec = 5.4 m/sec

Model’s Power and Kinetic Energy:

N $_{\textbf{model}}$ **(t=0.1 sec)** = v· (F – m · *g* – D) – 0.5 · m_{tsec} · V^2 =
= 5.4 m/sec (1.91 N – 0.0298 kg * 9.81 m/sec^2- 0.02 N) - 0.5 * 0.0021 kg/sec * (5.4 m/sec)^2 =
= 8.62 W - 0.03 W = 8.6 W

K $_{\textbf{model}}$ **(t=0.1 sec)** = 0.5 · m_{model} (v_{model})^2 =
= 0.5 · (0.030 kg - 0.0021 kg/sec · 0.1 sec) (5.4 m/sec)^2 = 0.43 J

Exhaust gases Power and Kinetic Energy:

N $_{\textbf{exh g}}$ **(t=0.1 sec)** = 0.5 · m_{tsec} · (V – V_e)^2 =
= 0.5 * 0.0021 kg*sec (5.4 m/sec – 919 m/sec)^2 =
= 865.8 W

K $_{\textbf{exh g}}$ **(t=0.1 sec)** = 0.5 · $m_{exh\ g}$ ($v_{exh\ g}$)^2 =
= 0.5 · (0.0021 kg/sec · 0.1 sec) (916 m/sec)^2 =
= 88.1 J

As you see, the Rocket engine (for the 1st stage) is not effective at the very beginning of it's operation, when velocity of a vehicle is almost 0.
In our case the rocket engine’s Power and Kinetic Energy, thrown into exhaust gases, are 100 and 200 times (respectively) greater than the Power (and the Kinetic Energy) transmitted into the rocket itself.

Actually, the same is true for an airplane’s jet engines as well. When you see very slow moving jet airplane at takeoff, huge flames of exhaust gases go to a wind. You can see, hear, feel it! Feel how much energy just being thrown away.

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6.1. Some Physics and Math behind a Piston (con’t 2)

This poor picture will be even poorer if we will compare the Propellant Internal energy (Calorific value) and the part of it transferred into a model during this 0.1 sec.
Calorific value of Black Powder
$q_{BP} = 2.7 \div 2.9\ 10^6$ J/kg.
Q (0.21 g of BP) = 580 Joules.

Than:
$\eta = K_{model}$ (t=0.1 sec) / Q (0.21 g of BP) = 0.43 J / 580 J = 0.00075 (or 0.075 %)

In the other words, only 0.075 % of the propellants internal energy is transferred into the Kinetic energy of a rocket.

It will be very good to give back to a rocket even part of that huge lost power and harness this high-temperature high-enthalpy flame.
We just have to contain these gases and box them into a confined volume of a solitary cell / chamber. And when we execute that, we will create … a piston.

This will utilize not the kinetic property of the exhaust jet but the gases internal energy (temperature and pressure). And we will come to the almost classical internal-combustion engine, in which the chemical energy of a fuel (commonly used liquid or gaseous hydrocarbon fuel) burning in the work area (combustion chamber) is converted into mechanical work, applying direct force to some component of the engine.
In this case of a rocketmodeling piston the work area is a combined chamber “rocket combustion chamber and above-piston-chamber”.
Moreover, a rocket combustion chamber acts as a hot-gas-generator for the work area of the internal-combustion engine.

Of course, even theoretically, it is impossible to transfer the entire power of an exhaust gases into mechanical energy of a rocket. Remember that the maximal value of an efficiency coefficient for the most sophisticated internal-combustion engines is about 45%. However, if we are able to harness even 5% of power, transferred to exhaust gases, it will result in net gain - gain 5 (!) times more power than the power, transferred into rocket due to the Law of conservation of momentum.

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6.2. History of a Piston Launcher development

Robert Hutchings GODDARD (1882–1945) – one of the fathers of modern rocketry, patented one of the earliest methods of boosting the launch of a rocket by capturing the energy of exhaust gas before it reaches optimum thrust (US Patent No. 2,307,125, "Launching Apparatus for Rocket Craft," Robert H. Goddard, Filed Dec. 9, 1940, issued Jan. 5, 1945)

ARCAS — was the designation of an American sounding rocket, which was launched between July 31, 1959 and August 9, 1991 at least 421 times.
A variant of the Arcas, Super Arcas, was used extensively around the world from a wide variety of platforms on land and at sea. With a boost from a gas generator fed launch tube, Super Arcas was capable of reaching altitudes as high as 100 km.

Wes WADA introduced “Augmenter Tube” (essentially short “piston” without moving parts) in his Research and Development report at NARAM-5, (Hanscom Field, Bedford, Massachusetts, 1963)

Gordon K. MANDELL published an article «The Wayward Wind» in «Model Rocketry» magazine (1969, May) with plans for closed breech launched models

Geoff LANDIS is a scientist at the NASA John Glenn Research Center, where he works on Mars missions and on developing advanced concepts and technology for future space missions;
and a science fiction writer who has won the Hugo and Nebula awards, and have published one novel, a collection of short stories, one volume of poetry, and a hundred or so short stories.
Geoff Landis did quite a bit of work on computer simulations of piston launchers during period 1970 to 1975.

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6.2. History of a Piston Launcher development (con’t 1)

George HELSIER Invented «**Standard**» piston launcher.

Trip BARBER published fundamental article on the basic physics of the piston launcher ("Pressurization Effect Launchers," Trip Barber, *Model Rocketeer, Vol. XVI,* No. 6, July **1974**, pp. 14-16)
Member of the USA national team (5 WCh: WCh-1978; -85 (individual «bronze» – S1); -2006; -08; -10)
Howard KUHN (1921-2010) served as the CIAM Space Models SC Chairman for 17 years (1979 – 1995), introduced many innovations to the model rocketry.
Member of the USA national team (2 WCh: WCh-1, 1972 (individual «bronze» – S7); WCh-2, 1974 (individual «bronze» – S5))
Chuck WEISS and **Jeff VINCENT** invented and introduced The Floating Head Piston Launcher in their Research and Development report at NARAM-28, August 1986.
Chuck WEISS - Member of the USA national team (3 WCh: WCh-1987; -90; -92 (team's coach))
Jeff VINCENT - Member of the USA national team (4 WCh: WCh-1980; -85; -87; -92 (individual «gold» – S1))

Vladimir MINAKOV - Member of the USSR/Russian national team (5 WCh: WCh-1987; -90; -92; -94; -96. 3 WCh individual «silver» – all in S5. 3 EuCh individual «gold» – 2 in S5; 1 in S8)
Stanislav ZHIDKOV – Coach/manager of the USSR/Russian national team for 29 years (1977-2005), 12 WCh.
Victor KOVALEV - Member of the USSR national team (2 WCh: WCh-1987 (individual «gold» – S8); -90).
Alexey KORIAPIN - Member of the USSR/Russian national team (12 WCh: WCh-1983 through 2006 3 WCh individual «gold» and 1 individual «bronze» – all in S1).
Coach/manager of Russian national team (2006-present).

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6.2. History of a Piston Launcher development (con’t 2)

Mikhail POTUPCHIK (RUSSIA, Miass, Cheliabinsk region), pioneer the use (Russia's championship –1995) of the idea of holding down the model and piston to build up pressure before first motion (with Kevlar thread) – POTUPCHIK's «Behemoth» piston launcher
Mikhail POTUPCHIK - Member of the Russian national team (1 WCh: WCh-2002
Mikhail POTUPCHIK, Vladimir ISAEV, Andrey SEMIONOV (RUSSIA, Miass, Cheliabinsk region) published an article with schematics and numerical analysis results for piston launcher with receiver chamber («“Piston” revisited», Modelist-Konstruktor, (Russia), No 5, May 1996, pp. 20-21)

2010. **Robert PARKS** and **Ryan COLEMAN (both USA)** introduced “The Pacific Flying Machines (PFM) Piston”. This R&D was a successful implementation of the earlier author’s (Robert PARKS) idea (2006) of holding down the model and piston to build up pressure before first motion.
Robert PARKS - Member of the USA national team (3 WCh: WCh-1978; -80; -83)

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6.3. Schematic of original “zero volume” US piston

Observing S1 models take-off using pistons during the Capital Cap-2011, I did not notice any visual or sound effects from the piston. At least it was not similar to the effect of those I had been familiar with. In fact, the pushing impulse/force of a Russian-style piston is so great, that it can be noticed by a naked eye and by a naked ear. Several times I have even observed cases when the entire launcher was unearthed and fell to the ground. What kind of impulse is required to pull out a metal stick, which obviously was put to the ground with a great force in the first place? A few times a relatively thick bottom membrane (2…3 mm) of the Stop Nut made out of duralumin (see slides below) was broken as a result of the piston tube stroke.

But those “ancient” pistons which I saw during the Capital Cap-2011 were, in fact, the same pistons, as I saw the first time almost 30 (!) years ago during the WCh-1983 in Poland. Surprisingly, nothing has changed in piston design among US modelers since Howard Kuhn introduced his invention about 40 (!) years ago.

Interesting that 5 years ago in his report about the WCh-2006 in Baikonur Trip Barber (USA) mentioned: “… anyone who does not have a European-style piston launcher (far beyond US technology levels) is not a medal contender.)”

Even since then, during the last 5 years nothing has changed.

Predecessor of the European-style piston is … Geoff Landis design of the "zero volume" piston launcher. However, Europeans made some changes to the original US piston design.

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6.4. “Fathers” of European-style piston (Russian piston)

This is the story

Somehow a sample of the US piston got to the Laboratory of the Palace (Minakov School). It was a simple steel rod with a brass cylinder (piston head).

For several years it was laying among old models.

Finally, back in 1986 I decided to make my own version. I replaced the rod with a tube, put wares inside the tube to make an engine’s ignition from inside and made the main tube from epoxy-fiberglass.

During the national team practice / selection in Georgia I tested this launcher.

The very first flight demonstrated a difference. Even the difference in sound was an indicator that there was something worth of investigating / researching / developing.

Almost everybody came to the conclusion that this type of launcher has hidden potential. And with an appropriate design it could provide a substantial advantage.

Within a year a new basic Piston was designed specifically for S8 models.

A group of 3 Moscow modelers - MINAKOV Vladimir, KOVALEV Victor, ZHIDKOV Stanislav (by some coincidence all three are Moscow Aviation Institute graduates) and KORIAPIN Alexey (Murmansk) came up with the design, which is currently (a quarter century later) still in use with some improvements. Later on the design was adapted with some variations and is used by entire FAI European spacemodeling community (but not the US).

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6.5. First results of Russian Piston application

1. The class of Radio Controlled Rocket Gliders (S8) was included the first time as an official FAI category in the WCh-1987 (Yugoslavia). KOVALEV Victor (USSR) became the 1st World Champion in S8. And one of the key factors of his success was a new “European-style piston launcher”.

A year later, in 1988 a smaller version of the same design was applied to S1 and S5 models and even to the free-flight categories S3/S4/S6.

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6.5. First results of Russian Piston application (con’t)

2. MINAKOV Vladimir became the European Champion (with the “MMR 06” prototype and … a new piston).
Since then almost each and every European and World champion in the altitude categories (S1 and S5) got their titles with a piston assistance.

So, these “European-style pistons” owe to the original American - Howard Kuhn design - predecessor and partially to that sample lost among dusty models and pieces parts in Moscow RM Laboratory, and the collective brain-storming and R&D by the group of modelers from Moscow (+ Murmansk). And in that way it will be more correct to call this design not just an “European-style”, but to be more specific: a Russian Piston, and even a Moscow Piston.

However, the name of a piston, and how it is actually called in Russia, Ukraine, and in all other former Soviet Union republics among rocketeers, is another story. A Story within a story…

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6.6. Russian Piston Name

Back in 1986, my 1st testing flights with a piston.
KUZMIN Victor (may the peace of God be with him) pronounced with his great smile: “Pu-u-u-k”, imitating the sound of a model take-off from a piston tube. Then he came to me and said: “You sure “puked” well, Alex!”
The word “puk” in Russian imitates sound of … excuse me, “fart”.
Then “puk” and “puk and “puk”. And this word was glued to a piston as a name and spread out through the entire spacemodeling community of the Soviet Union.
About two years later Stanislav ZHIDKOV, a National team coach/manager complained to me about choosing such a discordant word for a piston. He felt it was about time to make it prohibited calling it “puk”.
I responded: “Yes, sure, especially if that name was given by such a striking-word-maker as Victor KUZMIN –
“Oh, yes, not likely! And now it is impossible to extirpate the word” - was his response.
…
And now the word “puk” is a sort of the official name for a piston.

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6.7. Comments on piston design

6.7.1. Engine-Tube fitting

One of an American piston disadvantages is engine-tube tight fitting and corresponding friction and velocity-loss during model-from-piston separation.
That issue was solved by:

- A ring-shaped divider / membrane (between engine and a piston head);
- A Silicone Sealant

Thus, after the engine’s ignition exhaust gases can’t get under engine but get into the head-end volume. The engine with model will not jump off it’s fitting but will stay connected with the piston’s tube and will move up with it since the pressure force against the divider membrane = ($S_2 \cdot p_2$) is greater than the pressure force against the nozzle base = ($S_1 \cdot p_1$).
These adjustments allow loose fitting engine-tube with a lesser friction at the separation point.

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6.7. Comments on piston design (con’t 1)

6.7.2. Quadruple threads

Quadruple threads of the fastening parts on top and on the bottom of the tube allow faster assembling/disassembling operations.

6.7.3. Igniter

The igniter (of course with appropriate preparation) provides a faster igniter insertion and more reliable ignition.

6.7.4. Tube ID - Piston Head OD Gap

Gap between Tube ID and Piston Head OD is about 0.12 - 0.14 mm..

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6.7. Comments on piston design (con’t 2)

6.7.5. Tube’s vent holes location

Originally vent holes in the bottom were made at the base of a Stop Nut. Recently the holes are made usually on the tube.

6.7.6. Tube’s wall thickness

Tubes are made out of 2 layers of fiberglass (Δ=0.06 mm) / or (the most resent approach) 1 layer of Kevlar (Δ=0.12 mm).
Additional strengthening is required at the top (for resisting high temperature exhaust gases) and at the bottom (to prevent cracking and destruction of the “shell with cutout”, which is especially sensitive to a shock loads).

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6.9. BOM

Metal ski poles were used as mandrels (usually ∅ 15 mm) to make Piston Tubes.

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6.10. Piston Cleaning

In order not to mix anything we used commercially available and easy to get at any place product.

”Lyrical digression”
Funny episode took place then, at the WCh1990.
USSR team in S1 (Koriapin Alexey, Kuzmin Victor, Mitiuriev Alexander) won team gold in the event, despite that our team had only 2 results, Victor Kuzmin final result was “O” – technical issues (DQ) and track loss. However, the other teams, which used 2 stage models in the category, also had DQs among their members, or successful flight results of all 3 members were too low (due to single-stage models). New technical requirements for model’s body “30x350 mm” led modelers of the world to build and use 2 stage models in order to be competitive. However, reliability of the models and their traceability were very poor for WCh - 9 “Zeros” final results among 30 participants in the event.
Victor Kuzmin joked then: “Don’t reproach me about zero result, you better look and see – what kind of the medal I have for the event!”
Actually, it was the only case in the entire history of the WCh in spacemodeling when a “Zero” final individual result was awarded with the world team title.

Formally, spacemodeling sport is an individual sport, with team competition/result being simply the sum of individual results. However, it is a TEAM sport, with mutual support and help from and to each other.
Victor Kuzmin was always a TEAM person. And in this unique case his help and support turn into individual success of the other team members (gold and silver) and into the team highest place (1^{st}), despite of his own “0”.

The TEAM and its atmosphere, with a mutual support and help are the greatest key success factors.

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6.11.3. Reducing the weight of the Piston’s moving parts

A. Replace relatively heavy duralumin (ρ = 2.7 g/cm^3) used for fastening parts (see Piston’s BOM: Engine fitting Sleeve, Threaded Sleeves (top and bottom), Stop Nut) with lighter but strong and shock loads resistant material(s) (for example: Kevlar-Carbon-Epoxy).
The weight of these 4 parts (made out of duralumin) is about half the weight of the piston’s moving parts (12.2 g vs. 22 - 27 g, see BOM). Using lighter material(s) can potentially reduce a total weight of the Piston moving parts by 20%.
B. Removing Threaded Sleeve (top) – replace the Top fastening couple with Engine fitting Sleeve glued into the Piston Tube.
However, this change will result in reduced mobility, and inconvenience of piston parts assembling/disassembling for cleaning-launch preparation purposes.

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6.11.6. Developing and improving new piston launcher devices.

See **note B** for par. **«5.1.1. Engines Thrust diagram / burn time»** concerning model’s (1st stage’s) design approach.

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7.1. Material. Dimensions. Shape

A. Recommended material

Metallised Mylar (polyethylene terephthalate), thickness Δ = 10 … 12 μm
I will not recommend thinner material, it is not strong enough;
Thicker material is too heavy and it will be too wasteful to “spend” weight on something that is not at the very top of a stage.

B. Recommended shape and dimensions

Despite the absence of the minimal streamer dimension in the current 2011 version of FAI Code I will still designate 25 x 350 dimension within a streamer. However, in order to make it lighter, taper it. It will cut streamer weight at least in half and save us about 1gram.

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7.2. Body-NC-Streamer attaching

Replace a traditional rubber shock cord ($\varnothing \approx$ 1 mm, weight per unit of length $\approx$ 0.1 g/dm) with almost weightless (m < 0.05 g) a zero-rebound stroke shock-absorber.
Zero - rebound shock absorbers can be made out of Kevlar thread coiled between 2 layers of a masking tape.
Usually the length of the rubber cord is about 10 cm (+). Correspondingly, the weight of it is about 0.1 g at least.
An application of these shock absorbers is particularly important for S6 category due to its small weight.
For S1 this shock absorber can be a good solution especially in a case of relatively heavy NC loaded with Lead (density 11. 34 g/cm^3), Tungsten (density 19. 25 g/cm^3), Gold (density 19. 30 g/cm^3), Platinum (density 23. 45 g/cm^3), … (it is up to you) to optimal 2^{nd} stage weight.

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8.1. Ignition of 2^{nd} Stage engine. Reliability improvement

One of the most important issues in the design and operation of multistage models is a reliable ignition of the upper stage engine.
The overwhelming majority of modelers are using flash tubes to ignite the upper stage engine.
It is recommended to make them from carbon–fiberglass to make this tube lighter.
I suggest tube ID of 3.0 mm for engines with diameter 10 - 13 mm.

8.1.1. Fabrication of a Flash Tube

- Coat a substrate (plastic, Mylar or thick foil) with an epoxy layer and put fiberglass on top of it (thickness of 0.025 mm).
- Put a piece of carbon fabric on top and coat it with epoxy.
- Put a steel rod on a wide edge of fiberglass. Lift the very edge of the fiberglass from a substrate and stick it onto the rod along the fabric edge. Coil fiber glass-carbon onto the rod.
- Sand the surface of the tube (if it is necessary) after epoxy polymerization.

Tube OD is about Ø 3.25 … 3.5 mm, depending on carbon fabric thickness (0.08 mm for lesser diameter, 0.16 mm for greater) with a specific weight per unit length of about 2 g/m and 4 g/m respectively.

- Thermal treat epoxy IAW recommendations for the applied epoxy type

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8.1.2. Black Powder granules padding

Press a few (3-5) granules of BP into the engine’s nozzle.
Be cautious to not damage the nozzle’s surface.
Use a backside of a drill bit with a diameter slightly smaller than a nozzle diameter.
Note that the engine’s propellant is monolith. The presence of black powder granules in the nozzle will increase the lateral surface. These BP granules have a small ignition energy
level and will catch the fire beam from the tube and ignite the engine.

8.1.3. BP charge in a bottom stage engine

Put the BP charge on top of the 1st stage engine.
It is recommended to put this charge at the very end of a model preparation for the launch – just before joining the 1st and the 2nd stages, in order to avoid accidental pouring-out of this BP charge. Pour BP charge through funnel, fitted on top of the flash tube.
BP charges are measured with a measuring gauge made out of a cartridge case for a small-caliber rifle (ID 5.6 mm) depending on the flash tube's length:
- For a tube length of about 150 mm – the length of PB charge should be 4 mm.
- For a tube length of about 300-350 mm – the length of PB charge should be 6 mm.

Have successful IGNITIONS!

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8.2. Testing

To increase the reliability of your model, to find the most rational (possibly optimal) solution/ design, you should test your model and/or the prototypes of your model.
For the best outcome and for the time reduction to achieve a goal you need to create a Test Plan and follow it, sometimes adjusting it, depending on the testing results.

8.2.1. Ground testing

The most reliable testing are full-scale flight tests. But sometimes for a resolving some of the problems the ground testing is less expensive (in term of time and money). Ground testing can be more informative than flight testing, with a better ability to see the process right in front of you and even to photo and film it for further detail analysis.

8.2.2. Flight testing

In order to verify your design and the model’s parameters you need TEST FLIGHTS.
In order to be prepared to launch your model in windy condition, you need TEST FLIGHTS.
In order to make a comparative analysis for different design schematics you need TEST FLIGHTS.
In order … you need TEST FLIGHTS.

- Flight Log

It is very desirable to record your tests. Actually, information about any flight: test, practice or competition should be reflected in your Flight Log.
Recorded information should contain not just seconds/meters, but should be more complete, for example:

- Initial weight;
- CG location;
- Engine(s) type;
- Factual delay time / apogee achieving time;
- Wind velocity during launch;
- Model’s tilt angle at launch;
- Deviation from vertical line during launch, etc.;
- Some additional comments.

All that data will help you to analyze different designs / design approaches to correct technical solutions, technology.
Don’t rely on your memory, record this data.
Sometimes it is difficult to measure everything. Ask for help from your colleagues-rocketeers, and help them with the same.
Very often there is no time to record such “seemingly unnecessary” data.
Trust me, sometimes there are not enough of that lost data in order to make a CORRECT decision during the model’s design/fabrication /testing and during competitions themselves.
This statistical data will help you to use each test flight intelligently, rationally and more effectively.

Transfer the test data into an EXCEL file. It will help you to visualize results of your model(s) flights.
You can also include information about your colleagues models flights into your database (if you have such an opportunity) in order to have a «wider picture» and to have a better knowledge of “where to go” for an improvement.

- Altimeters
Try to use altimeters (if it is possible) for every test flight of your models.
For references: a light altimeter (total weight “Altimeter + Battery” ~ 1 gram) is being developed currently in Russia.

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8.2.3. Some recommendations for Flight Tests preparation and conduction

Consider the following general recommendations, when prepare and conduct test flights.

8.2.3.1. Flights number

In order to minimize impact of:
- External factors (first of all - wind) and
- Internal factors (first of all differences in total impulse of engines, and differences in used testing models) you had to make not just a single test flight but a row of at least 3 (or even 5) flights for each case / compared option for reliability of obtained testing results

Besides, number of necessary tests/flights is the subject for special research. But I can assure (omitting "jungle" of mathematical statistics and model’s physics/mathematics) that just one flight won't give a reliable answer to your question(s).

8.2.3.2. Test models quality and uniformity

Differences in test models (or difference between the models and their drawing) should be minimal if you use several models for testing.
Otherwise you will not research what you want (for example impact of design options onto the flight altitude), but will research impact of fabrication carelessness onto the result.

8.2.3.3. Weather conditions during testing

Use calm windless condition for your test flight in order to minimize weather conditions onto testing results.
Conduct your flight testing within as short time interval as possible in order to minimize weather conditions changes (wind speed; air density, temperature, pressure).

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8.2.3.4. Engines selection for flight tests

Engines for testing should be specially selected in order to minimize their spread in performance.

Engines should be:

- Of the same batch (since raw materials (propellant, first of all) are different for different batches; vary in composition, mixture homogeneity, grain size, etc.);
- Of the same OD, with tolerance less than +/- 0.02 mm;
- Of the same weight with smallest tolerance;
- Of the same propellant charge height.

In reality, it is possible to measure the height of «nozzle+propellant» charge only, but not the «propellant» charge:

- Drill a hole (ID of about 2-3 mm) through delay charge. Drill off center, but not near engine’s wall. Drill manually. Use drilling jig made out of aluminum alloy
- Measure height of «nozzle+propellant» charge
- Fill up the hole with epoxy.

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8.2.3.4. Engines selection for flight tests (Con’t)

- Engines Static Test.

I recommend to conduct Engines Static Test (for total impulse measurement) of several (two-three) engines among already selected IAW the above-stated criteria In the case if flight testing with flight altitude measurement is accompanied by the comparative numerical analysis (flight altitude calculation) in order to use more accurate total impulse value.

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8.2.4. Second Stages Separate Flight Testing

To research 2nd stage parameters I recommend separate 2nd stage flight testing (without 1st stage) for flight testing - research of 2nd stage options/performance in order:

- Saving of the 1st stage engines;
- to reduce the impact of:
  - Spread in performance of the 1st stage engines (the most important – spread in Total Impulse);
  - Spread in stages separation;
  - Errors in math methods/models of a 1st stage flight (in the case if flight testing is accompanied by numerical analysis).

Of cause, consider that 2nd stage flight velocity (including average and maximal (burnout)) is lower for separate flight than for flight WITH 1st stage. However, the difference should not impact most data and conclusions, obtained from the 2nd stage separate flight testing.

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8.2.5. Flight Testing to determine body's airflow regime

In order to answer the question «Is there really a Laminar b/l along a cylindrical part of the model’s body?», you can make a number of flight tests.

8.2.5.1. Comparison of the calculated and measured flight altitude

Practically we had to solve «a flight dynamics reverse problem» – to “reestablish” the average value of Cd $_{total}$ on a base of measured flight altitude, and to draw a conclusion about the predominant flow type (Laminar or Turbulent) on the base of comparison of calculated (for Laminar and Turbulent b/l) and measured flight altitude values.

Since flight altitude values for Laminar and Turbulent b/l are sufficiently differ from each other (the difference is about 20 % for used above mathematical model), I suspect that, it will be not difficult to draw the conclusion about a flow type.
And on the basis of this conclusion, in particular, to make a decision on BT option (see par. **«1.3.2. Length of 2nd stage BT»**)

However, Comparison of the calculated and measured flight altitude values may not give a clear and authentic answer to the question about predominant B/L type, due to several reasons, including:
- Accumulation of the errors of mathematics model being used in the numerical analysis;
- Errors of the assumptions (see par. **«1.2. Cases under consideration and assumptions»**);
- Mathematical models inaccuracy of drag coefficients values for model’s parts (NC, body, BT, BS, fins), see par. «**1.1. Numerically simulated model of Cd $_{total}$».**

For this reason I recommend also the following.

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8.2.5.2. Direct comparison of the measured flight altitudes with and without turbulator

In addition to more complex (with accompanying numerical analysis, flight altitude calculation) you may use much simpler method (yes, this one will require twice as many of testing flights). And what is important, this method is more correct and direct one.

1. To Insert an element, which will certainly turbulize the flow, but at the same time which will not impact noticeably onto the rest (if it is possible) into a "critical" region (where transition from a laminar to turbulent flow is the most probable), NC Parabola – Body’s Cylinder juncture point: attach a thin thread/strip onto this line.
2. Conduct series of testing flights with such turbulator and without it.
3. Compare the flight altitudes.

In the event of:

A. The measured results are approximately identical, or the option with a turbulator has a slightly less altitude (due to the reason described above, see par. **«1.2.3. Location of a Laminar-to-Turbulent flow transition point**»)
This will indicate that the flow is practically Turbulent at the body’s cylindrical part during the entire flight (i.e. at different flight velocities).

B. The difference between the measured results are approximately 10-15 %:
$\Delta H/H \approx \Delta Cd_{total} * ((\partial H / H) / (\partial Cd_{total} / Cd_{total})) \approx 0.2 * (0.6\text{-}0.7) \approx 0.13$

This will indicate that the flow is practically Laminar at the body’s cylindrical part during the entire flight (i.e. at different flight velocities).

C. The difference between the measured results are substantially less than 10-15 %.
This will indicate most likely that the flow at the body’s cylindrical part for the option without turbulator is Laminar only at relatively small flight velocities.

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10. Key success factors of the past World Champions

All information presented above concerned mostly technical issues:
- Models;
- Engines;
- Launching devices.

However, other aspects and factors of success are important too.

On the one hand – with availability and application of altimeters, which provide a higher level of result’s objectivity and accuracy - technical factors will play a major role in achieving great results.

On the another hand – with current technical information exchange level, and a substantial increase of communication (compared to 20-30 years ago) between modelers via internet and direct contacts during competitions (which increased in numbers, specifically the World Cap events) - those other “non-technical” factors will play their important role too.

Basically, you can not hide your technical advantages without exposing them during competition. And when everybody is on the same technical level (or within minute margins), you will need something extra in your baggage and you will need to squeeze everything from everything.

Two to three years ago I posted material “How to become a champion” on the Russian Spacemodeling web site (www.frms.ru), where I described other, mostly non-technical factors to achieve success. Yes, modelers at the national team level generally know them. However, this information put together can be interesting and useful. I guess, I will translate it into English and put it into PPP format as well.

Meanwhile, let’s see what were the key success factors among titleholders of the WCh in the past, the ones I have knowledge of.

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10.10. WSMC-2012 S1. Gold medal - TIMOFEJEV Maksim (LTU)

1. Very good engines (Piotr Sornowski’s (Poland) design & fabrication):
1st stage: PSn A8-1-1: Specific impulse $\mathbf{I_{sp} \approx 1500\ N \cdot sec / kg}$
Small delay time $\mathbf{t_{delay1}} \approx$ **0.6 sec**
Small delay time for 1st stage engine allow to Prevent Total Impuls loss (See par. «**5.1.4.**3. **Prevention of a Total Impuls loss for 1st stage engine**»).

2nd stage: PSn A1-4-8: Specific impulse $\mathbf{I_{sp} \approx 1200\ N \cdot sec / kg}$
Long burning time $\mathbf{t_{burn2} = 4\ sec}$,
Which allow substantially reduce a/d velocity loss (See par. «**5.2. 2nd Stage Engine»**).

As it was suggested in the earlier version of present material (Rev. 3, par. «**5.2. 2nd Stage Engine»**), the longer burning time for 2nd Stage Engine (than t_{burn2} = 1.5 sec of Taborsky’s “Delta A-2-7” and Hapon’s “Zenit A-2”) might increase the total flight altitude…
…*What a surprise. Who can predict that?*

Long delay time $\mathbf{t_{delay2} = 8\ sec}$
Engines (traditional delay) is producing low (but different from zero) level of thrust during delay time (coastal flight). Moreover, by reason of imperfection of FAI Code, and some times due to imperfection of measuring instrumentation for value of total impulse measuring very often thrust level during delay time is not measured. And total impulse of burning delay is not included into engine's total impulse in these cases.
Did such things take place at WSMC-2012? – I don't know.
But even that took place, it was applied to every participant of the competition. And everybody were under equal conditions …, *almost* under equal conditions. *Almost*, because models (2nd stages) of the leaders, those whose models are more aerodinamically advanced (with a lower value of $\mathbf{Cd_{total\ 2}}$) and have longer coastal flight (because these models are decelerating slower), and therefore might have longer engines delay time. Due to this reason, all other things being equal, along with longer delay time, come a greater «additional» total impulse.

4. Preparedness, composure and readiness during contest.
Indication of such readiness was the fact that Maksim TIMOFEJEV, by the way, along with bronze medallist Zoran KATANIC (SRB) launched their models at the very beginning of the contest – among the first participants – as it turned out later, these particular flights brought medals to both of them.

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11. They are HIGH because they are TALL

And now … forget about all of that math - optimization, physics, models building / best fabrication techniques, etc. Forget about everything has been said above. The only thing that matters in S1 event is how … TALL YOU ARE.
This is a paradox. But the fact is, the most successful rocketeers in S1 event on the USSR (and later Russian) national team were … the tallest members.

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11. They are HIGH because they are TALL

Short story.
It was my debut as national (USSR) team member at the international competition, European Championship – 1981 (Bulgaria).
After a successful team selection competition among team member candidates, I got a special assignment from team coach/manager Stanislav Zhidkov to develop and to build S1 models for team members.
So, team members in S1, SOLDATOV Yuri, KUZMIN Victor, MITIURIEV Alexander had been competing at EuCh-1981 with identical models, being built IAW the same design by the same pair of hands.
The final result of the EuCh-1981 in S1:
SOLDATOV Yuri became the first Soviet (Russian) European champion.
Yuri was at the time the tallest member among the entire Soviet team.
But even more, by a strange coincidence, individual places in S1 among the Soviet team members (with IDENTICAL models!) were tabulated IAW their own … height.
And there is another funny story within this story…
It turned out, that the only team with multistage models in S1 event was our team (USSR).
Somebody asked me when the competition was completed: “How did you get your rocket so high? What was the key success factor of your team’s great results in S1?”
I tried to be clever: “It was the application of the Tsiolkovsky idea about a “rocket train”“ [as he, Tsiolkovsky called the multistage rocket].
Victor KUZMIN, who was standing about added with teasing sarcastic intonation: “Tsiolkovsky, Tsiolkovsky … Already in remote antiquity a Russian peasant used to say: «The heavier a load, the … hell with it!»”,
referring to a loaded horse cart (of ancient times) and to jettisonable burned-out rockets stages (of the current century).
Yuri SOLDATOV (1951 – 2012) - Member of the USSR national team (2 WCh: WCh-1978; -83).
Victor KUZMIN (1945 – 2006) - Member of the USSR/Russian national team (5 WCh: WCh-1983 (individual «silver» – S6); -85 (individual «gold» – S4); -87; -90; -92).

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11. They are HIGH because they are TALL (con’t 1)

2. Alexey KORIAPIN (the tallest among Soviet/Russian team members at that time) became 1st (among Soviet/Russian team members) twice and then tree-time world champion.
And all his titles were won specifically in S1.

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11. They are HIGH because they are TALL (con’t 2)

3. When Oleg VORONOV became a Russian team member, he also got the title of «tallest among team members». And along with that (within a time) became the most successful modeler in Europe in S1 category IAW European Championships results – 3 individual titles (!).

It looks like there is some strange hidden correlation between a modeler’s height and altitude results. It is easier for tall contestant to reach altitude – they are already there, «at an altitude » / «on high».

They are HIGHER, because they are TALLER.

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12.1. Rocket Science (Aerospace Engineering)

Presented materials are eclectic, which reflects the “polyphonic” nature of spacemodeling and concerned about subjects in different areas. That reflect a complex / multi-voice nature of the “big brother” – the aerospace science / industry.

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12.2. Rocket Science / Spacemodeling and … Symphony Orchestra

Building models and competing at competition in some ways are similar to … conducting a symphonic piece, where each instrument counts and crucial to success to the performance of the entire piece depends on the successful performance of each and every musician in the orchestra.
How harmonic and balanced it was composed in the first place.
How it was performed – in the second place.

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12.3. Space / Rocket modeling

Of course, your models and their design are not as complex as real rockets. However, major issues are present in your models as well (on a smaller scale and in a smaller capacity).

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12.4. Tabulated results of the World and European championships in S1 during the last 28 years. Margin from 1st place

Result margins between 1st and 2nd places have been shrinked.
During the last 6 years (the last 5 championships) results of the 10 top contenders were within 15% of the leader's results.
In these circumstances every, even small improvement can be decisive for a final result.
But what if you can apply everything I said above? … It is up to you.
The general trend is (as you can see from the diagram) the results densification in time. And it will be logical to assume that in the future this tendency will continue. This also reflects the overall trend of margin reduction between contenders in the highest athletic feats in *competitive* sports with objective results scoring (including Olympic disciplines).

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12.5. Statistics on more than one medallist of the world and Europe championships in a certain category from one team during the last 28 years (since 1985) in the various categories

The following statistics is interesting.

During the last 28 years (since 1985) at **22** world and Europe championships (the technical results of «top 10» of which are presented in thiis material (see par. «**9. Technical results of the past World and European Championships (top 10 contenders)**»), the technical results of only 2 Europe championships (2nd ECh-1988 and 3rd ECh-1991) are missing for this period of 28 years) in **S1 category**:

1. At least 2 representatives of one team are among the medalists of the individual event at **15** championships (i.e. in **2/3** cases**, 68.2%,** the highest number among other categories).

2. One of the-same-team-medalists was a **gold medal winner** at **11** championships (i.e. in **half** cases**, 50%,** the second highest (after S8) number among other categories).

3. The-same-team-medalists were a **gold** and a **silver medals winners** at **7** championships (i.e. in almost **1/3** cases**, 31.8%,** the second highest (after S5) number among other categories).

There is no similar «the same-team-crowdness on a podium» paradox in any other class of models (except for the class of (there again) **altitude** models, scale-altitude models (**S5**), where certainly the factor of availability (of photos and drawings) and the factor of using the advantageous prototype by members of a top-step-podium-team of the specific championship had an impact always and prevailed very often).

The number of teams participating at the international competitions during these 28 years has been increasing. And it would seem logically that the podium picture should become more motley with an appearance of representatives of various national teams. In the certain sense, that's just the way it was/is – new teams have been appearing. But the podium in S1 individual event has been changing mostly «by team» - passed from one team to another. And this tendency of the podium “capture” (2 out of 3 medals) by representatives of one team in altitude category persisted during latest championships as well. And the picture/ statistics / sampling, run on the more recent championships, for example during the last 18 and/or 10 years (similar to presented on the slide (for the last 28 years)), would keep the same tendency on prevalence of S1 on «the same-team-crowdness on a podium» measure among the other categories.

Such the «podium anomaly» of S1 category is just the confirmation and the reflection of the fact, that a successful technical solution (and most likely a combination of solutions among other factors) found and applied into models (usually models are similar (or even identical) in design and characteristics among members of the same team) has been giving an advantage over competitors, being expressed into the final result – the winning meters. And statistically this advantage in technical solutions application had been confirmed by not only one team member, but at least by two.

Factors of all the changes and chances of Fortune's wheel have the least effect in S1 category in particular. And what you put into your model at the design-fabrication-testing phases will be reflected later to a greater degree (greater than in other classes) into technical results and individual placing.

In this context S1 category is the most grateful.

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12.6. Your Nobleness, Sir LUCK

Yes, one of the most important key success components is luck.

And LUCK has been present in some way and had its own role in each and every case of the European and the world championships.

Sometimes it was luck of trucking the highest achieved result, and actually the highest flight was eventually rewarded with the title.

Sometimes it was luck, that the best result(s) of the future titleholder’s competitors were not trucked.

Sometimes it was just lucky that incompetent judges considering that it was the flight of “their” modeler, trucked/calculated it (like actually they should do anyway without division between us-them), and intending to throw the results in their own team favor made mistakes that resulted in their opponent’s victory.

And sometimes it was bad luck. Bad luck of competing in an alien field with cheating judges who did not see / or did not WANT to see.

And I hope there will be no such cases in a future.

However, Sir LUCK will always be there, with you or with somebody else.

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12.7. Everything is in your hands

When you are playing cards, the result (win or lose) depends on your skills (experience) and the luck of your hand.

But in our game, called spacemodeling, you can select cards for your hand prior to the game (competition). And it is up to you how many Aces, Kings and trumps your hand will have. It is in your hands to increase your good luck and to decrease bad luck.

You can choose one or a few things from described above. You can go with the full spectrum and /or go even further.

Or you can choose to do nothing. But don’t be surprised if somebody else has a stronger hand.

Make your own premium hand.
Don’t bet in the dark!

Remember that each and every improvement will be directly reflected in the final results - ALTITUDE. You can not cheat it.

In other categories you can probably (to some extent) compromise altitude with your experience: “My models do not fly very high, but I can get results with my weather / thermals feeling experience” (or something like that).

You can not do that with ALTITUDE itself. Not in S1!

However, I do not recommend neglecting an altitude in the other classes as well.

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12.8. Resources management / Time management

It is desirable to find the best / optimal solution in each of the mentioned (and not mentioned as well) above aspects above аспетов ….
One of the professors who taught me at the Moscow aviation institute, Vasili Pavlovich MISHIN (*), was not favourable to the terms «OPTIMIZATION», «OPTIMAL solution» (in regard to aerospace systems, design versions, …), but used term «RATIONAL solution». In some ways the academician (who worked at the top of the space-rocket industry for almost 30 years) was right.
It is not absolutely correct to use the term «OPTIMIZATION» regarding to technical systems from a mathematical (where this term came from) standpoint. And it's use without any necessary conditions, complements is not correct, since in reality (and not «on a paper») you always had to deal with constraints and limitations:
- limitations of existing technological level in general and technologies specifically available for you;
- on materials availability;
- time, available for the development - fabrication - testing of the given model;
- other available resources, including financial. Not everything and not always you can make by yourself, using available for you tools. Sometimes you had to order some fixtures, tools, parts, etc.

We are all human beings and our lives do not lock only onto rocketmodeling. And all of us like to spend our extra time for various things. And in order to build good models you need TIME, a LOT OF TIME. Essentially those of us who win this race against time and will be able to stretch it's frames as an espander will be successful, not only in rocketmodeling but also in other areas of our lifes.
It doesn't matter how much time you have. Time is always finite. You had to use it wisely. Eventually the winner is not the one who spent the most time for preparation, but the one who did it sagely.

This raises the issue of what is called in business the «**Resources / Time management**».
It is necessary to plan your activities to be completely ready and prepared at the time of competitions. Practically, to «saw-and-plane» until the last moment before a competition is a chronic ailment of many modelers. And they don't have enough time for very important phases as assembly and flight testing and that lead into rushed final preparation. You know by yourself that this usually come to no good.

When planning and scheduling your building-models-preparation activities you can approach from both sides of «time».
You know the date of the competition.
Your model(s) should be completed as a first approximation, let’s say for example, 10 weeks (or some other period of time, depending on your personal plans, the sports season schedule, etc.) prior to the competition in order to perform full flight testing and to have enough time for necessary corrections /changes into a design depending on results of these test flights (see par. **«12.10. Iterativeness of the New Model Process»**).

Competition date can not be moved – it is cemented! In this context models / modelers have to some extent tougher conditions in comparison with real rocketry, where date of rocket launches can be rescheduled upon a technical unreadiness.
Rocket model competition will take place «rain or shine» at the pre-arranged time – regardless of your and your models preparedness for a sertain competition, with your participation, or without you.

Your work schedule should have partial testing, for example, 2nd stage separate flight testing (see par. **«8.2.4. Second Stages Separate Flight Testing**») which should take place before the full flight testing.

It is more or less clear what and in what sequence should be included into work schedule/ plan in the other - «forward direction» of the time scale. Do you need any researches to be performeed (for example to determine the geometry and other parameters of your models) or you will use parameters based on an available information about models of the current leaders in the category? It is up to you to decide.

Build your work schedule, extrapolating in time the realization of the shedule's phases IAW available resources and desired goals.
Two shedule's «branches» (the one built «from the future» – from a competition date and another – built «from today») should be closed at some point.

*) - **MISHIN Vasily Pavlovich** (1917-2001), Academician of the Russian Academy of Sciences. One of the founders of the Soviet practical astronautics. First deputy of Sergey Korolev (1946-1966) and his successor as Chief Designer and the head of design bureau OKB-1 (presently S.P Korolev Rocket and Space Corporation "Energia") (1966-1974).

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12.8. Resources management / Time management (con't)

Check the fulfillment of a schedule.
Introduce the necessary corrections into the schedule.

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12.9. Priorities

There is a question of priorities.
What is it that you have to spend your time on is the most important and how far (deep) you should go in each direction to build a COMPETITIVE model?
Indeed, you can optimize models parameters on your PC and design-redesign your model till the cows come home, and then try to implement your design and to build «the best ever model», but in a hurry having missed some important issues. Or endlessly polish surface of the body, but hereby just only asymptotically approaching the better result, and later on to glue fins onto a shiniest body "by eye".

Everything has to be BALANCED. . . . .
At first I even wanted to grade, to prioritise various areas, topics and items for building a COMPETITIVE S1 model.
However, later on I drop this idea for a number of reasons:
- I can make mistake in a subjective estimation of such an objective topic in spite of the fact that maybe it is easier for me than for anybody else to make such a prioritization

- Much depends on «the digging depth» of each search directions. And if something is requered relatively a small attention / time, the other have to be present «as a given». For example, the fins-to-body assemblying should be done with means of a jig (not "by eye"); and models bodies fabrication - from epoxy-fiberglass (not from paper).
- Priorities themselves depend on many background initial factors, including the total available for you time to build S1 models, level of your experience in this category, etc.
- Also I wanted to leave something for your own creative search without polluting it with alien opinion.

Therefore, "How to prioritise the topics and up to what depth to develop each direction?" – It is up to you to decide!
While prioritizing the issues, just remember, that essentially EVERYTHING is important. The only thing is to determinate to what degree each aspect is important. Do not assume that one or two though brilliant idea(s), implemented in the model will let you draw away from everybody.
I met sometimes - the surprising thing is that even among modelers of expert level - those who claimed that their one-two super ideas being implemented into the model, will top everyone. But in reality such miracles do not occure! Everything is Important as a whole, in balance, a harmony. Otherwise, the ALTITUDE will simply punish you for your ignorance – arrogance.

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12.10. Iterativeness of the New Model Process

Remember that, the advanced models development (though, as in the real rocketry) has an iterative nature, and sometimes you had to make a few steps back and to correct an original design, and even to reject it after testing, … and as in the R. KIPLING's «IF»:
« … And lose, and start again at your beginnings,
And never breathe a word about your loss …»

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List of Changes (for Rev 4. vs. Rev 3.)

1. Slides 11-16 and corresponding «Notes», par. «**1.1.1. Aerodynamic skin friction coefficient Cf»**
New par. «**1.1.1.1. Location of Laminar-to-Turbulent flow transition point X_t**»

2. Slide 17 and corresponding «Note», par. **«1.1.2. Nose Cone Cd_{NC}»**
Added with approximating expression **Cd_{NC} (M, λ_{NC})** for the range of **$0.6 < M < 0.8$**

3. Slides 37-45 and corresponding «Notes», par. **«1.3. Numerical analysis results. 2nd stage»**
New par. «**1.3.4. Cd_{total} of 2nd stage = f(v) for X_t = f(V). Impact of a surface roughness»**

4. Slide 46 and corresponding «Note», par. **«1.3. Numerical analysis results. 2nd stage»**
New par. «**1.3.5. Cd_{total} of 2nd stage = f(v) for X_t = f(V). Impact of the body-NC juncture groove dimensions»**

5. Slides 74-75 and corresponding «Notes», par. «**3.1. Body’s external surface»**
New par. «**3.1.1. Minimal surface rougness and waviness»**

6. Slides 94-97 and corresponding «Notes», par. «**5.1. 1st Stage Engine»**
New par. «**5.1.3. Prevention of a Total Impuls loss for 1st stage engine»**

7. Slides 98-110 and corresponding «Notes», par. «**5.1. 1st Stage Engine»**
New par. «**5.1.4. Delay time for the 1st stage engine**»

8. Slides 113-114 and corresponding «Notes», par. «**5.2. 2nd Stage Engine»**
Added information on engines of Piotr SORNOWSKI (Poland)

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List of Changes (for Rev 4. vs. Rev 3.) (con’t 1)

9. Slide 179, par. **«9. Technical results of the past World and European Championships (top 10 contenders)»**
Added results of WSMC-2012 in S1

10. Slides 189-190 and corresponding «Notes», par. **«10. Key success factors of the past World Champions»**
Added results of WSMC-2010 and WSMC-2012 in S1.

11. Slide 199 and corresponding «Note», par. «**12.4. Tabulated results of the World and European championships in S1 during the last 28 years. Margin from 1st place»**
Updated with results of WSMC-2012 in S1.

12. Slide 200 and corresponding «Note», par. «**12. Conclision»**
New par. **«12.5. Statistics on more than one medallist of the world and Europe championships in a certain category from one team during the last 28 years (since 1985) in the various categories»**

13. Slides 203-204 and corresponding «Notes», par. «**12. Conclision»**
New par. **«12.8. Resources management / Time management»**

14. Slide 205 and corresponding «Note», par. «**12. Conclision»**
New par. **«12.9. Priorities»**

15. Slide 206 and corresponding «Note», par. «**12. Conclision»**
New par. **«12.10. Iterativeness of the New Model Process»**