Rev. 4 EN

S1. Strategy for success. Recommendations.

Prepared by

Alexander Mitiuriev

June, 2013

SEE NOTE

Author’s background

1. ~~Aerospace engineering education (MS). Working experience in the aerospace industry (both in~~

laboratory and industrial environments).

2. Member of USSR / Russian national team for 14 years (6 WCh; 5 WCh in S1).

   Personal achievements in S1: 1 European individual title; 2 individual “silver” medals at WCh.

   USSR / Russian team achievements in S1:
   - S1 is the most successful category (along with S7) among other events at the WCh for the USSR / Russian team among other categories.
   - USSR / Russian team is the most successful in S1 category in relation to other national teams of the world.

S1 Individual WCh Medals

#	Team	1	2	3	Total medals
1	USSR/RUS	6	6	3	15
2	SLO	3	1	3	7
3	USA	1	3	1	5

S1 Team WCh Medals

#	Team	1	2	3	Total medals
1	USSR/RUS	4	2	1	7
2	YUG	2	0	2	4
3	USA	1	2	1	4

3. Author came from the world-top spacemodellig “school” – Laboratory of Rocketmodeling of Moscow Palace of Children and Youth Creativity (Moscow Center for Youth additional Education). Teacher / Leader / Coach – Vladimir MINAKOV

3 pupils of the "school" are on the tops of the 4 ranking-lists, based on "Olympic" points: Individual "gold" – 3 pts; "silver" – 2 pts; "bronze" – 1 pt:

1.

World Championships

Rank # 1-
ILYIN Sergei

(USSR/RUS)

21 points:

2 6 3

2.

European Championships

Rank # 1-

LEVYKH Alexander (RUS)

21 points:

7

3.

Soviet Union Championships

Rank # 1-

ILYIN Sergei (Moscow)

33 points:

10 1 1

4.

Russian Championships

Rank # 1-

VORONOV Oleg (Moscow)

44 points:

9 6 5

Forward Notes

1. Some of the slides have remarks, explanations in the “Notes” part of the PPP.
   These slides are marked with **SEE NOTE**
2. All data are in metric: sketches dimensions – millimeters (mm);
   Altitude – meters (m); mass – in gram (g).
3. The current presentation’s subject is Altitude models (S1).
   However, some of the presented materials / conclusions are applicable for other categories – S3 / 6 / 9 and / or S5.

   These cases are marked with **Appl for S3/6/9** or **Appl for S5**
4. Some of the data has been obtained from the book “Flight Dynamics of Missiles” by Lebedev A.A. and Chernobrovkin L.S., "Mechanical engineering", 1973.

   Data, obtained from this book, is marked with **"FDoM"**

   The same data is presented in the book
   «Sport Scale Models of Rockets» by Vladimir MINAKOV.

   
5. Some of the conclusions in the presentation do not have clear answer(s). Some of the problems / selections between alternatives require additional R&D or/and a simple executive choice by the designer/modeler.

   These cases are marked with **TBD**

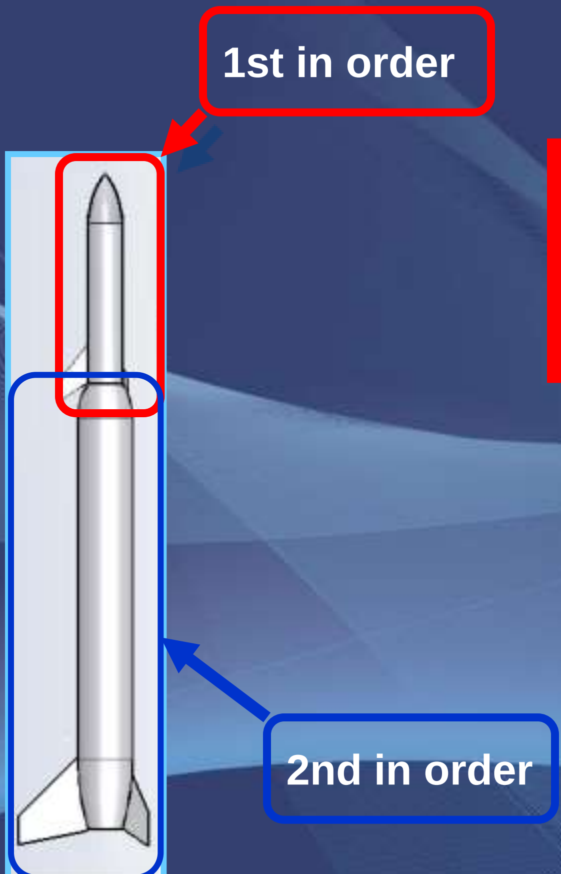
SEE NOTE

S1. Strategy for success. Recommendations

CONTENTS

1. Model geometry selection.

General design approach



Due to importance of 2nd Stage aerodynamic characteristics and their high impact on the final results (flight altitude), the geometry selection of the model should follow the basic principal:

One should select (optimize) geometry of the 2nd Stage and then optimize your 1st Stage based on the results.

This also will simplify the process of the selection. You do not have to vary parameters for both stages.

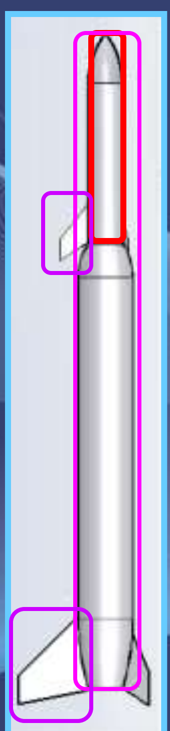
1.1. Numerically simulated model of Cd_{total}

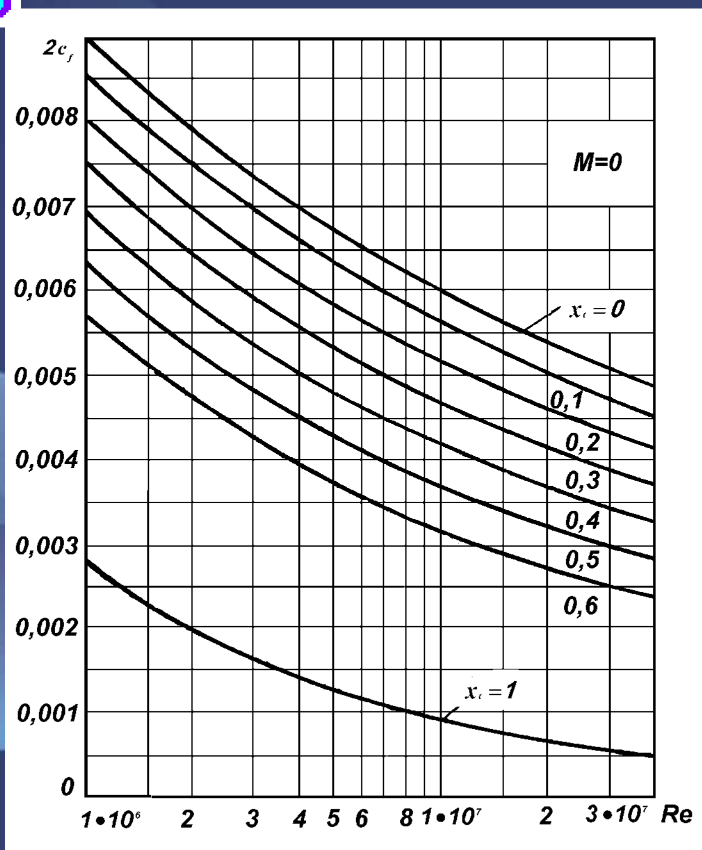
SEE NOTE

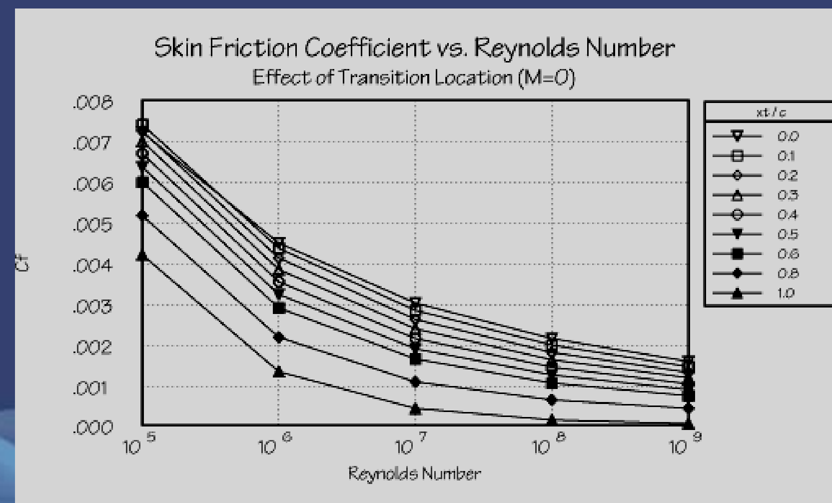
1.1.1. Aerodynamic skin friction coefficient C_f

Skin friction coefficient C_f vs. Re number and transition location X_t, M=0

"FDoM"



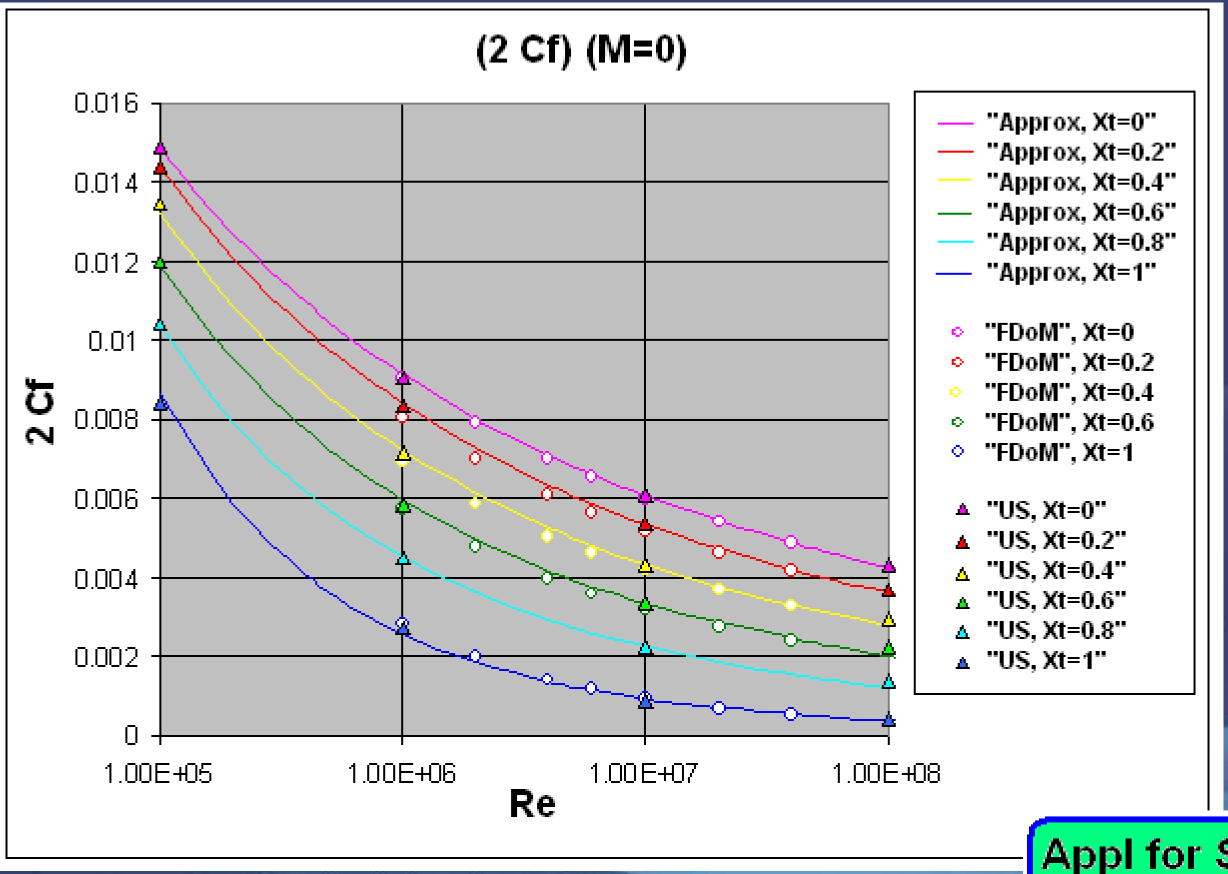


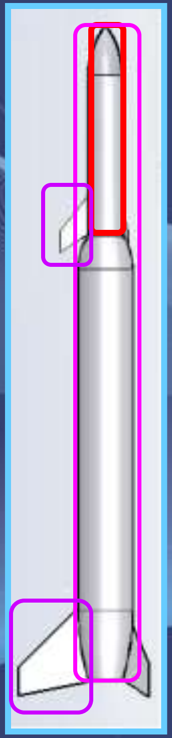


SEE NOTE

1.1.1. Aerodynamic skin friction coefficient Cf (con’t)

Graph interpretation of approximative dependence (2 C_f) vs. Re and X_t and comparison with the original sources:





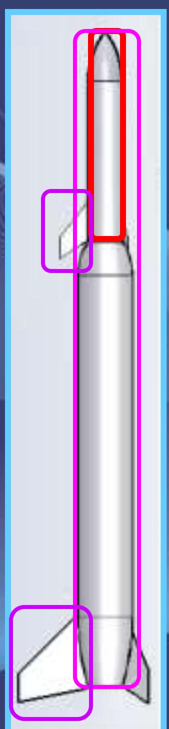
Appl for S3/6/9

SEE NOTE

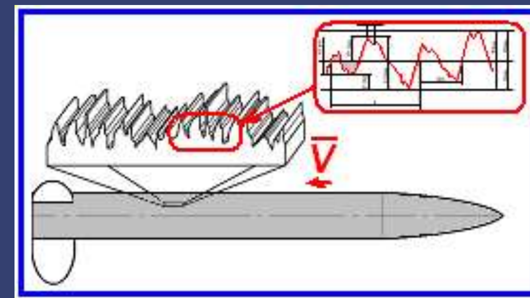
1.1.1.1. Location of Laminar-to-Turbulent flow transition point X_t

Factors, affecting location of Laminar-to-Turbulent flow transition point X_t

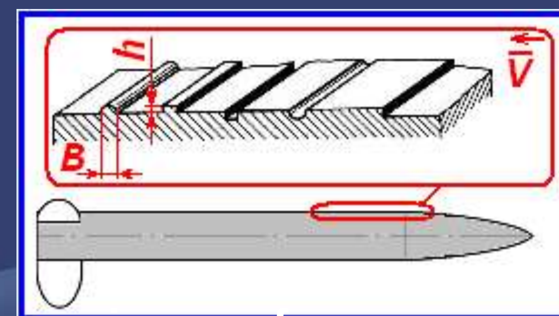
(critical Re value (Re_t)):



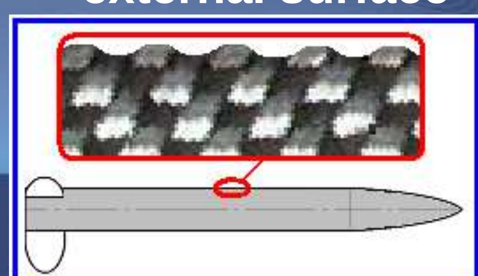
1. Roughness of external surface

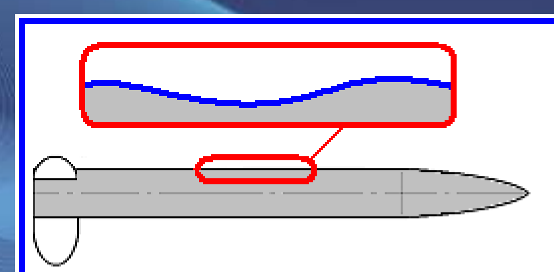


2. Single surface asperities



3. MICRO-waviness and MACRO-waviness of external surface

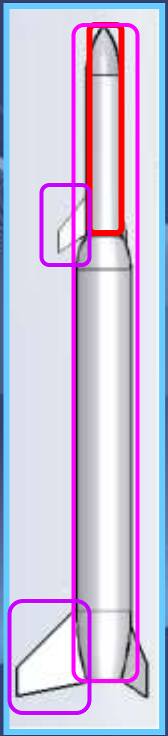


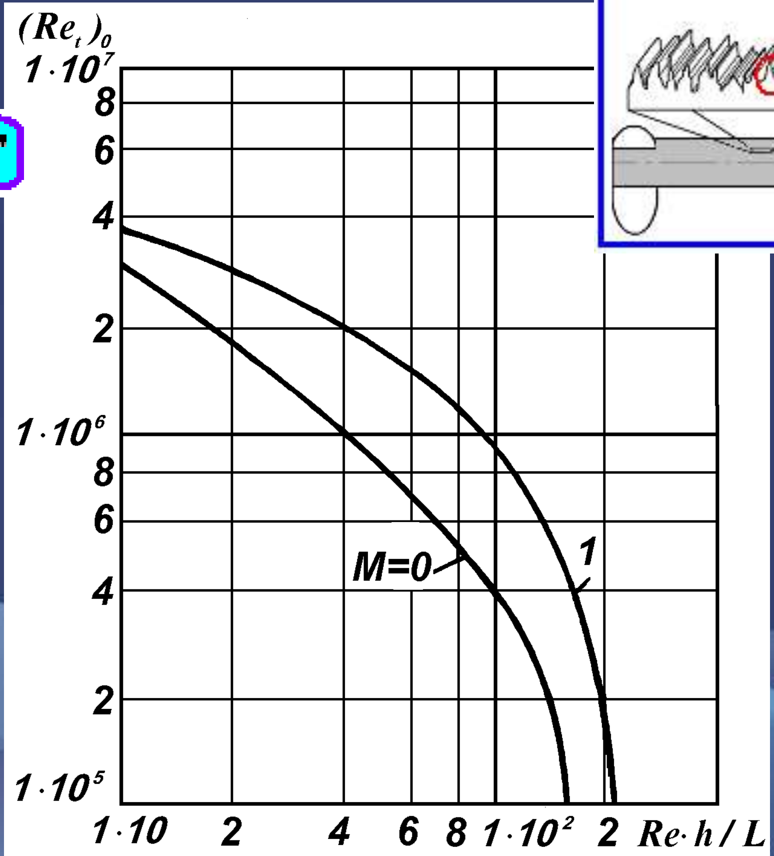


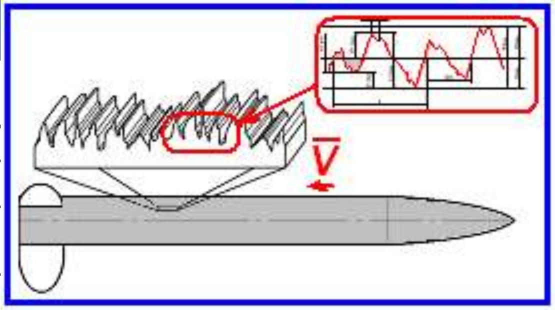
SEE NOTE

1.1.1.1.1. Impact of a surface roughness onto critical Re value

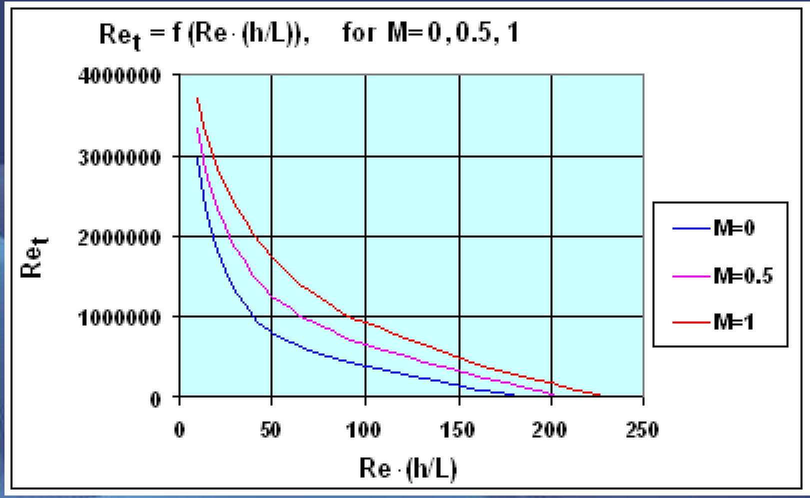
"FDoM"







Graphical interpretation of the approximation for critical Re value Re_t = f(value of surface roughness) :

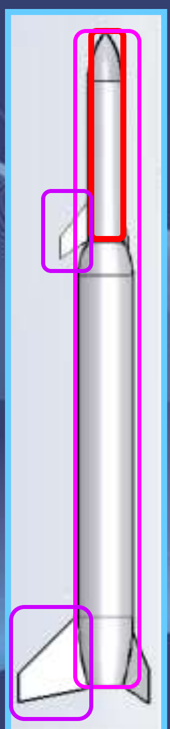


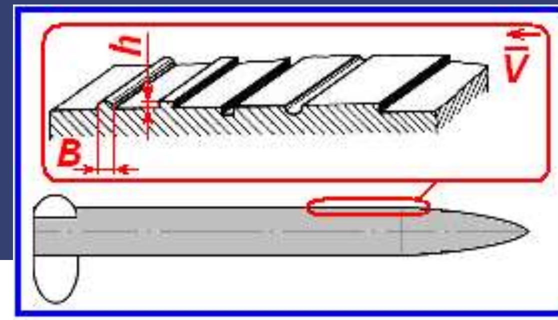
Appl for S3/6/9

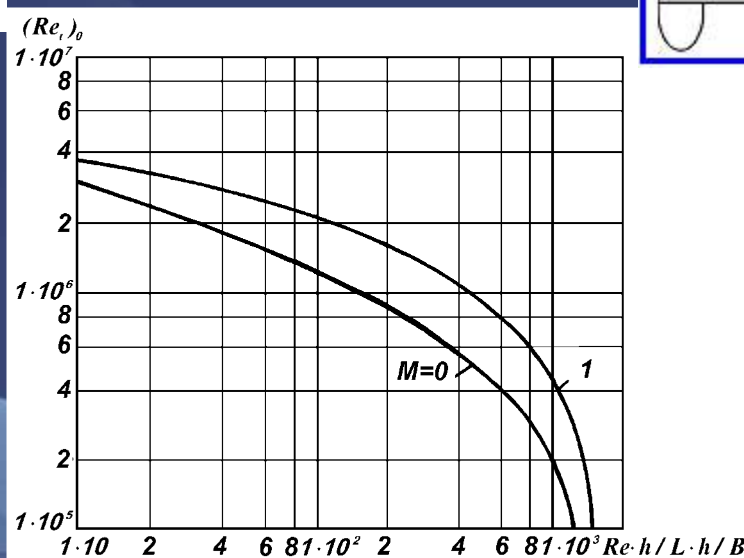
SEE NOTE

1.1.1.1.2. Impact of single surface asperities onto critical Re value:

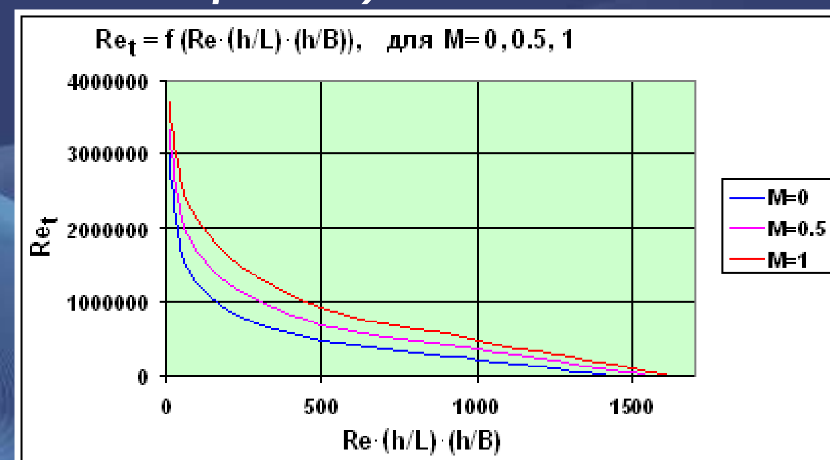
"FDoM"







Graphical interpretation of the approximation for critical Re value Re_t = f(dimensions of single surface asperities) :



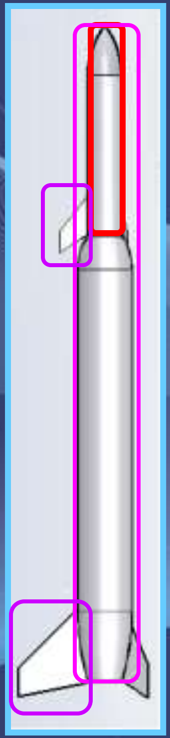
Appl for S3/6/9

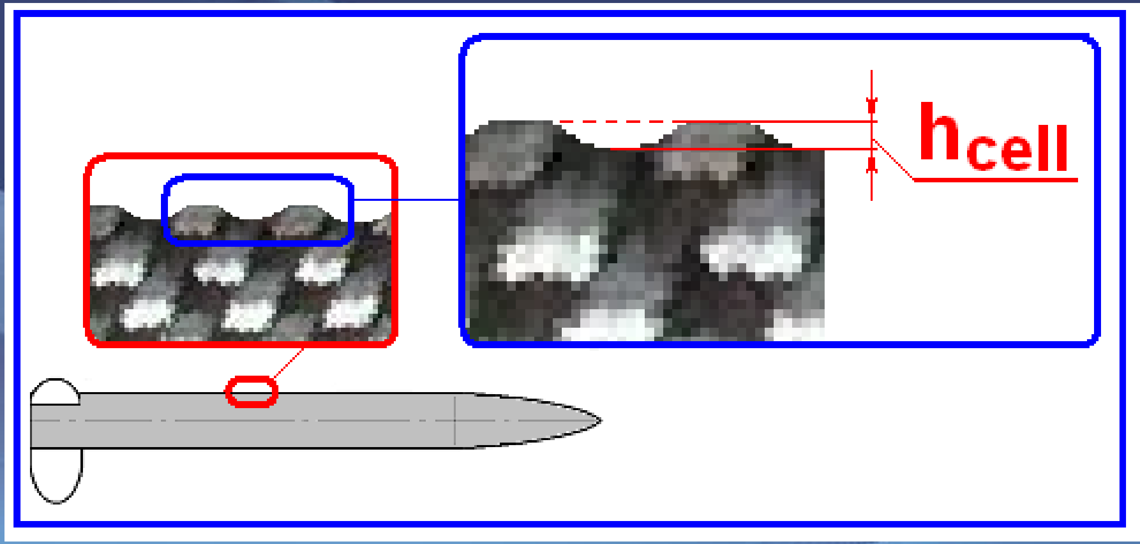
SEE NOTE

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

Guess value of the impact:

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





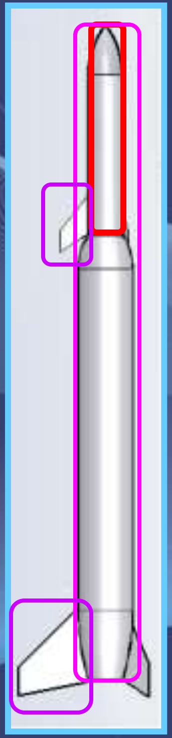
Appl for S3/6/9

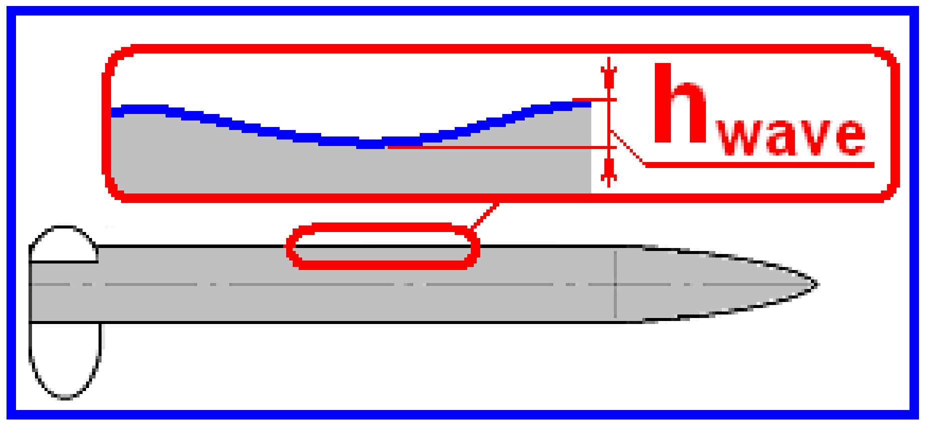
SEE NOTE

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

Guess value of the impact:

$$Re_t \text{ (MACRO-waviness)} = Re_t \text{ (surface roughness, } h = h_{wave}\text{)}$$





Appl for S3/6/9

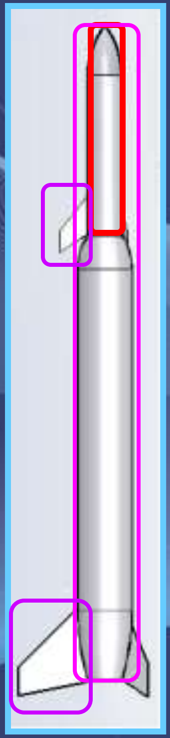
SEE NOTE

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

Guess value of the $X_{t\ sum}$:

Appl for S3/6/9

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



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**

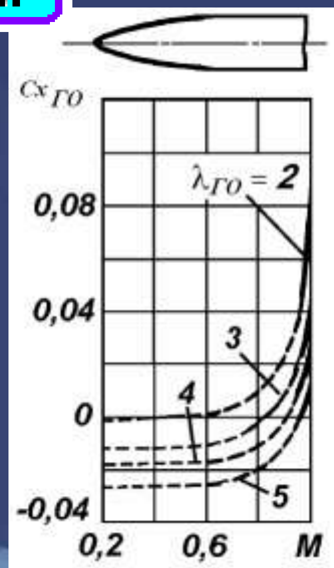
SEE NOTE

1.1.2. Nose Cone Cd_{NC}

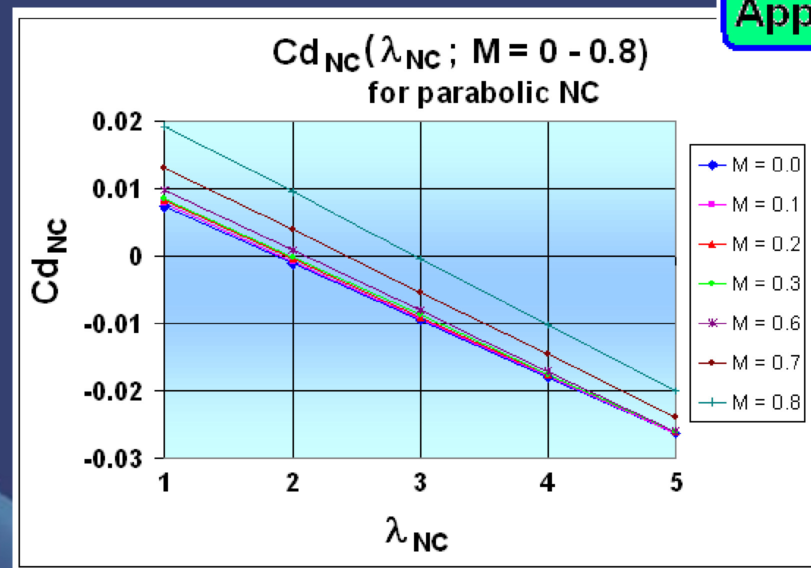
A. Cd for Parabolic NC with Generating line equation:

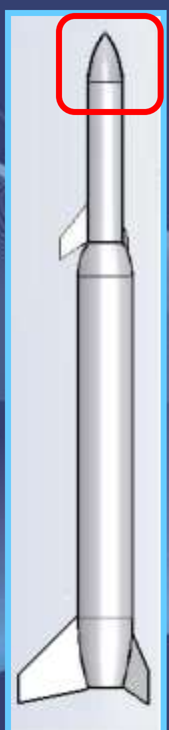
$$y/R = 2x/L_{ГО} - (x/L_{ГО})^2$$

"FDoM"



Appl for S3/6/9





for M < 0.6 :

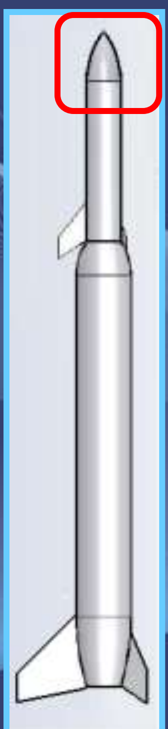
Cd_{NC} (M, λ) = (0.00517- 0.000933 * λ) * M + (0.0156- 0.00837 * λ)

for 0.6 < M < 0.8 :

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

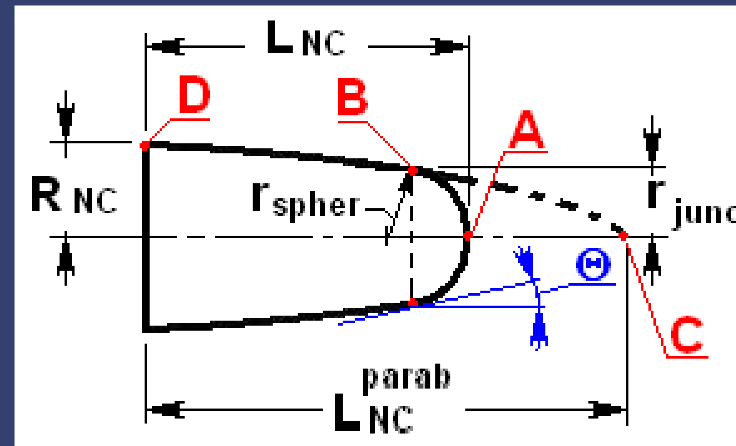
SEE NOTE

1.1.2. Nose Cone Cd (con't)



B. In case of combination of Parabolic and Spherical NC shape (with Parabola and Sphere are

tangent at the point of juncture):



$$C_{d\ sph/par\ NC} \approx C^{*}_{d\ par\ NC}\left[1 - r^{*2}\cos^{2}\Theta\left(3{,}1 - 1{,}4r^{*}\cos\Theta - 0{,}7r^{*2}\cos^{2}\Theta\right)\right] + C_{d\ sph\ NC}\ r^{*2}$$

Where: $C^{*}_{d\ par\ NC}$ – Cd for parabolic NC with length of $L_{NC\ parab}$

$r^{*} = (r_{spher}) / R_{NC}$

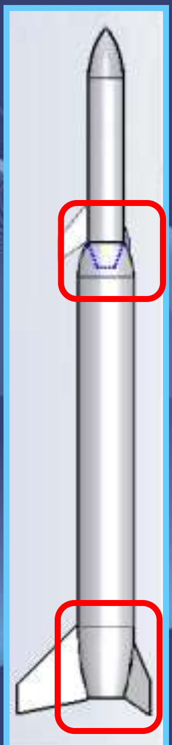
$C_{d\ sph\ NC}$ – Cd for semispheric NC (= 0.05)

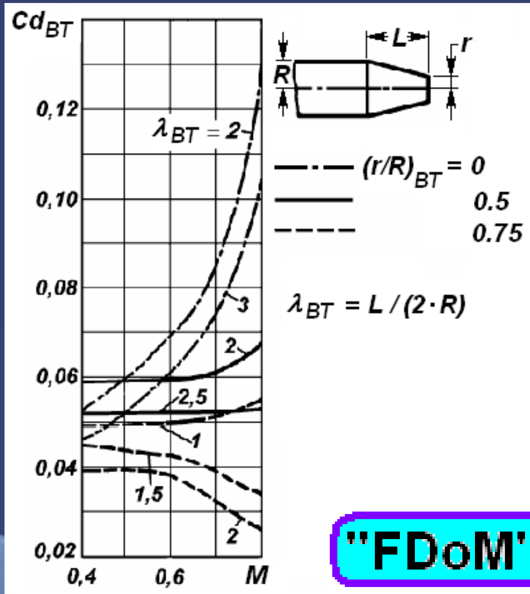
"FDoM"

SEE NOTE

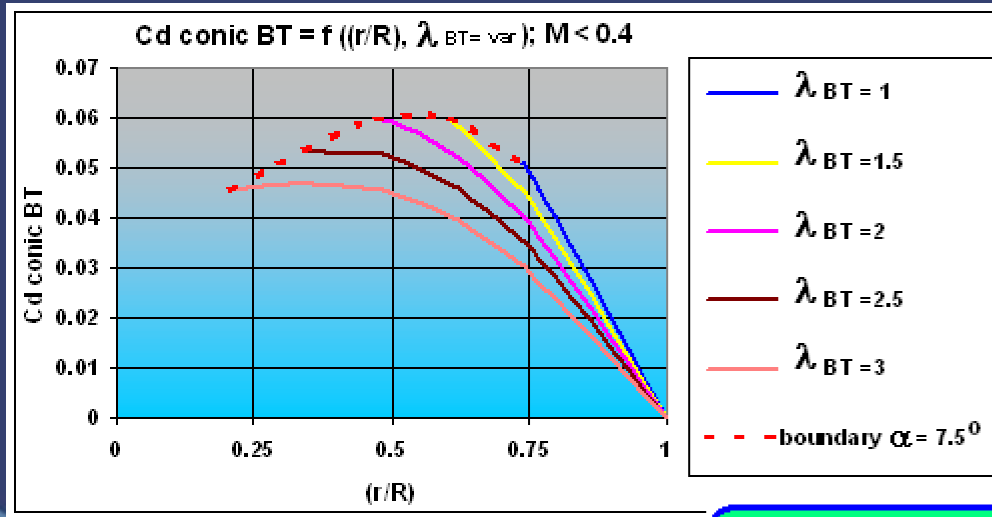
1.1.3. Boat Tail Cd

A. Cd for Conical BT:





"FDoM"



Appl for S3/6/9

$\eta = (r/R)$

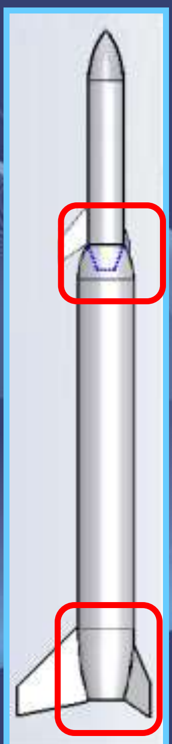
$$Cd_{BT}(\lambda; \eta) = (0.1456\eta^4 - 0.35003\eta^3 + 0.1313\eta^2 + 0.02458\eta + 0.04855) + (0.0161\eta^4 - 0.03418\eta^3 - 0.02388\eta^2 + 0.03734\eta + 0.00462) \cdot (2.0 - \lambda)$$

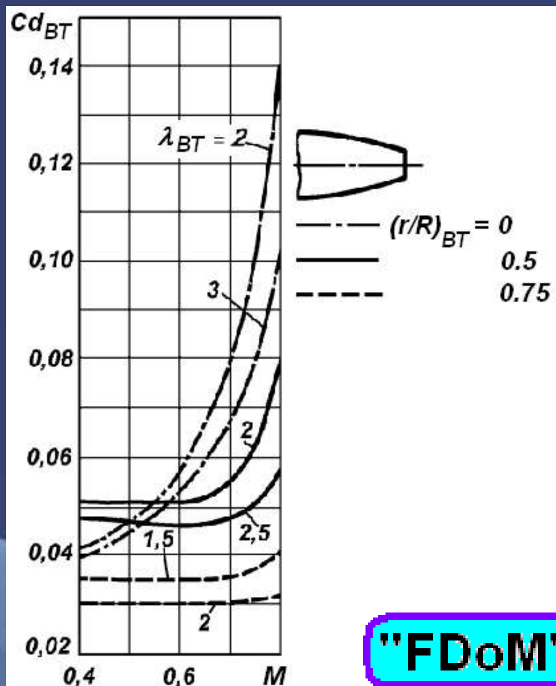
SEE NOTE

1.1.3. Boat Tail Cd (con't)

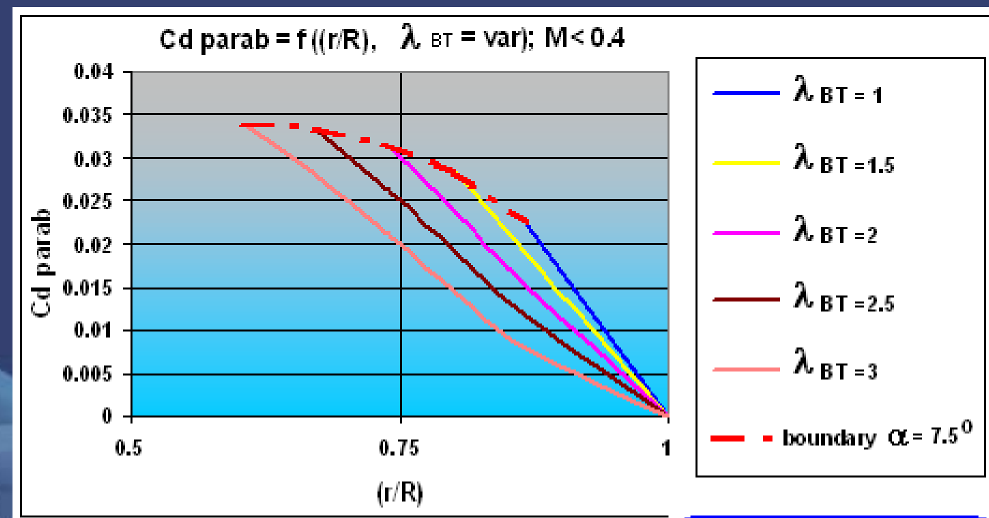
B. Cd for Parabolic BT with Generating line equation:

$$y/R = 1 - \left(1 - \left(\frac{r_{BS}}{R}\right)\right)\left(\frac{x}{L_{BT}}\right)^2$$





"FDoM"

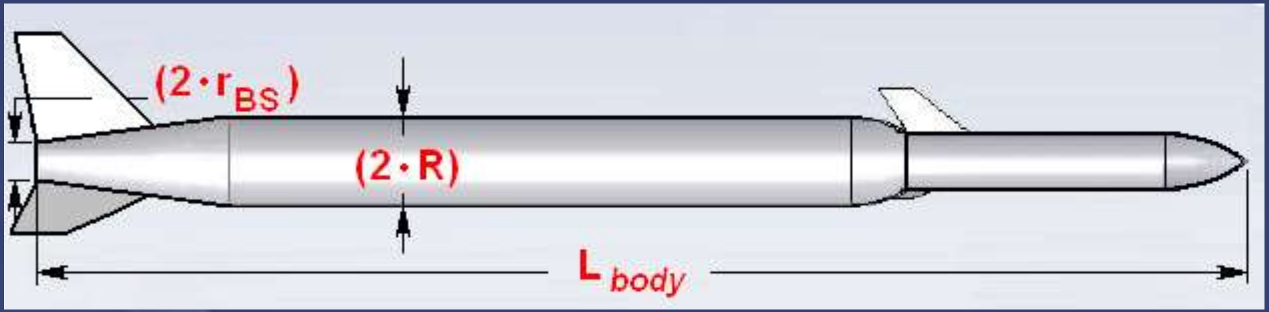


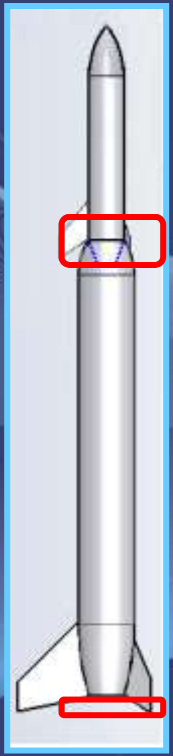
Appl for S3/6/9

$\eta = (r/R)$

$Cd_{BT}(\lambda; \eta) = (0.3002 \cdot \eta^4 - 0.6105 \cdot \eta^3 + 0.2654 \cdot \eta^2 + 0.0055 \cdot \eta + 0.0394) + (-0.04694 \cdot \eta^4 + 0.04266 \cdot \eta^3 - 0.01786 \cdot \eta^2 + 0.02014 \cdot \eta + 0.002) \cdot (2.0 - \lambda)$

1.1.4. Body Base Cd.





$$Cd_{BS} = \frac{0.0155}{\sqrt{(L_{body}/(2 \cdot R)) \cdot c_f}} \cdot \left(\frac{r_{BS}}{R}\right)^3$$

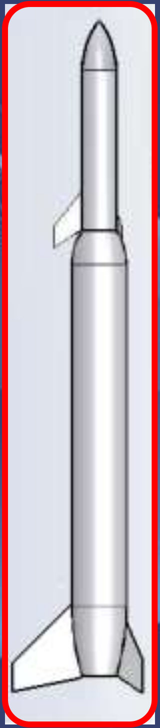
"FDoM"

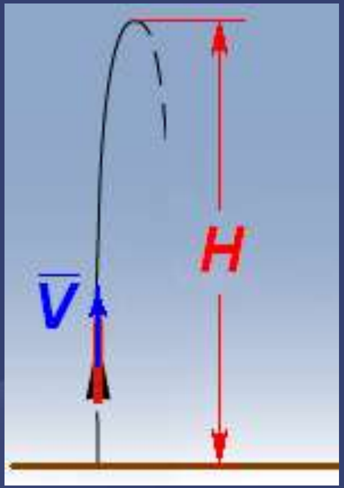
Appl for S3/6/9

Cf - Total skin-friction drag coefficient

1.2. Cases under consideration and assumptions

1.2.1. Assumption: min on Cd $_{total}$ (V $_{aver}$) correspond to maximum of flight altitude.





Model's parameters, which provide

min Cd $_{total}$ (V $_{aver}$)

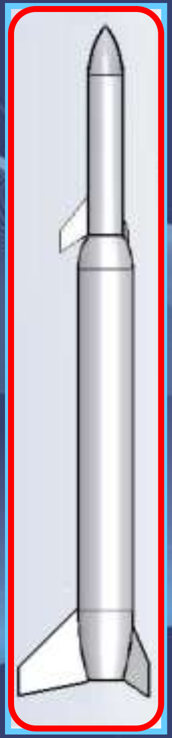
correspond to parameters which provide

max H $_{flight}$

CM. NOTE

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

Assumption:

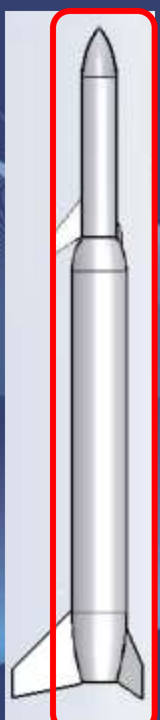


Cd_{Σ} equal to sum of model's elements Cds (NC, body, BT, BS, fins) :

$$Cd_{\Sigma} = \Sigma (Cd)_i$$

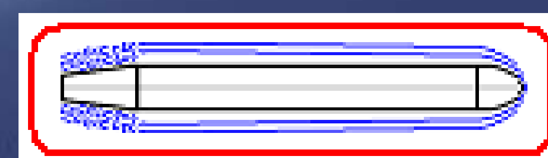
1.2.3. Location of the Laminar-to-Turbulent flow transitional point (Assumptions)

Due to importance of friction drag value, 2 extreme cases of the Laminar-to-Turbulent flow transitional point coordinate Xt were considered:

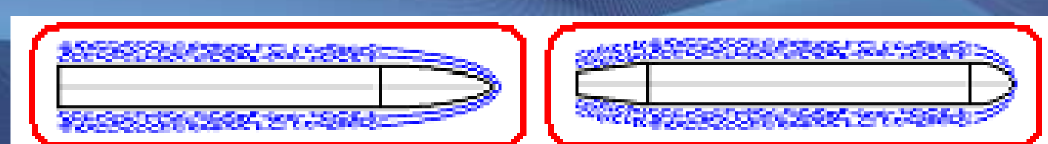


1. **Total Laminar flow (Xt=1) for totally cylindrical body (LBT=0).**

However, for Cylindrical + Conical (or Parabolic) BT body (LBT>0), Laminar-to-Turbulent flow transitional point's Coordinate Xt - at the Cylinder-BT juncture point.



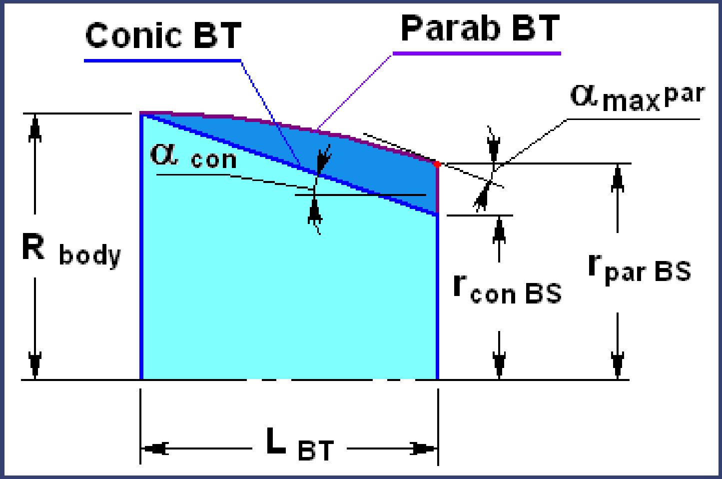
2. **At the NC-Cylinder juncture point.**



1.2.4. BT's shape (Parabolic boat tail vs. Conical boat tail)

For the fulfilment of the condition:

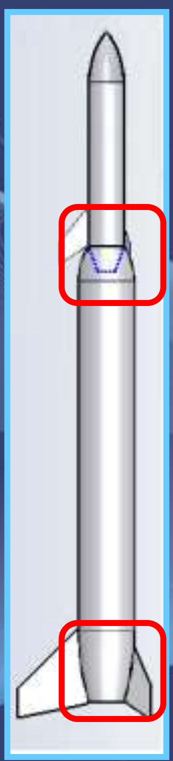
$$\alpha_{max\ par\ BT} = \alpha_{con\ BT}$$



In general:

1. For $r_{con\ BS} = r_{par\ BS}$
   $L_{par\ BT} = 2 \cdot L_{con\ BT}$
2. For $L_{con\ BT} = L_{par\ BT}$
   $r_{par\ BS} = (R + r_{con\ BS}) / 2$

Appl for S3/6/9



For cases under consideration:

$$\alpha_{max\ par\ BT} = \alpha_{con\ BT} = 7°$$

For 2nd stage (with engine's OD = 10.2mm), L_{BT} = 29mm

- Conical BT: r_{BS} = 5.4 mm
- Parabolic BT: r_{BS} = 7.2 mm

1.2.5. Fins

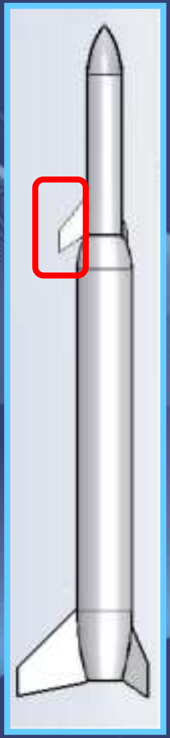
- **Fins Shape**

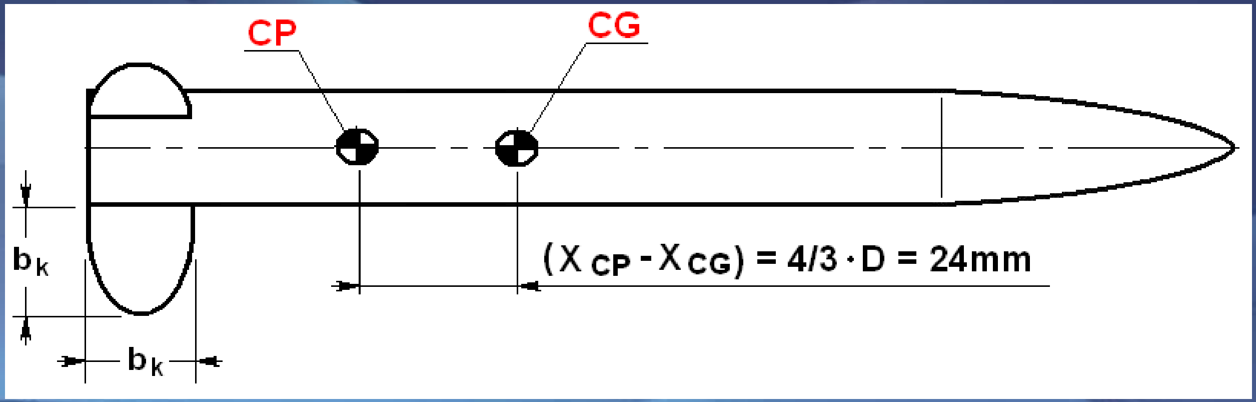
  For simplicity of the analysis:
  Fins are oval-shaped (close to elliptical shape) with semispan equal to root chord length.

- **Fins dimensions.**

  Fins total area (or dimension b_k) was taken in order to obtain static

  stability margin equal to 4/3 the caliber.



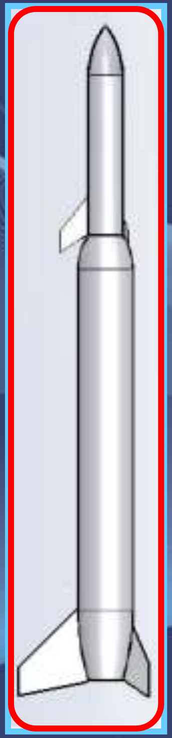


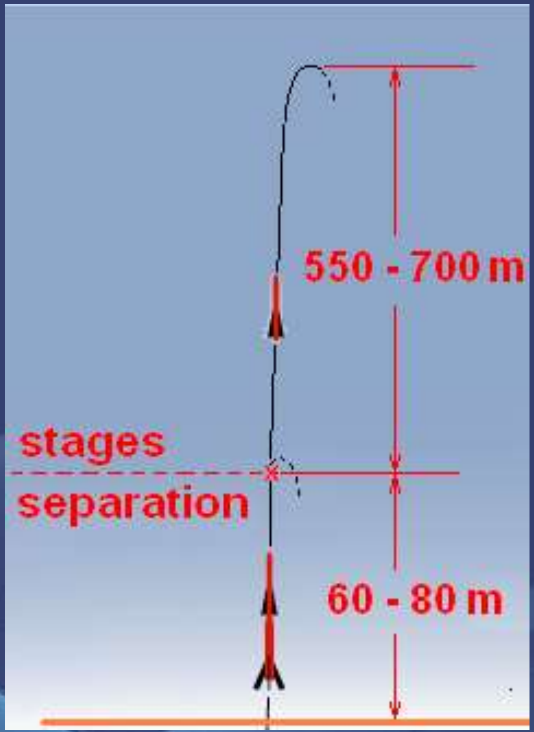
SEE NOTE

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

1st stage: **Cd_{total}** was calculated for

$V = 40$ m/sec $\approx V_{average}$ for 1st stage.





2nd stage: **Cd_{total}** was calculated for
$V = 80$ m/sec $\approx V_{average}$ for 2nd stage.

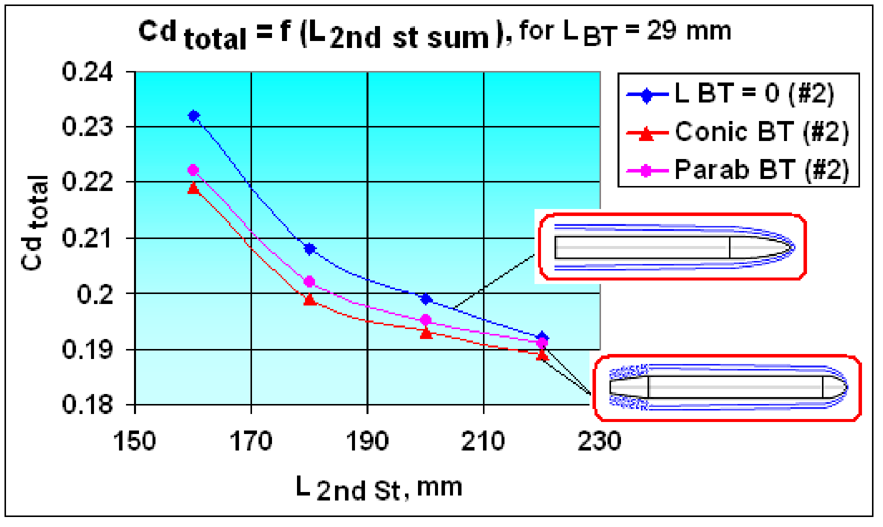
SEE NOTE

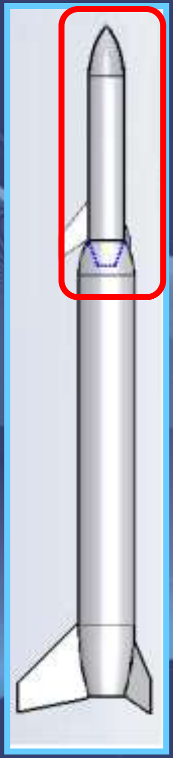
1.3. Numerical analysis results. 2nd stage

SEE NOTE

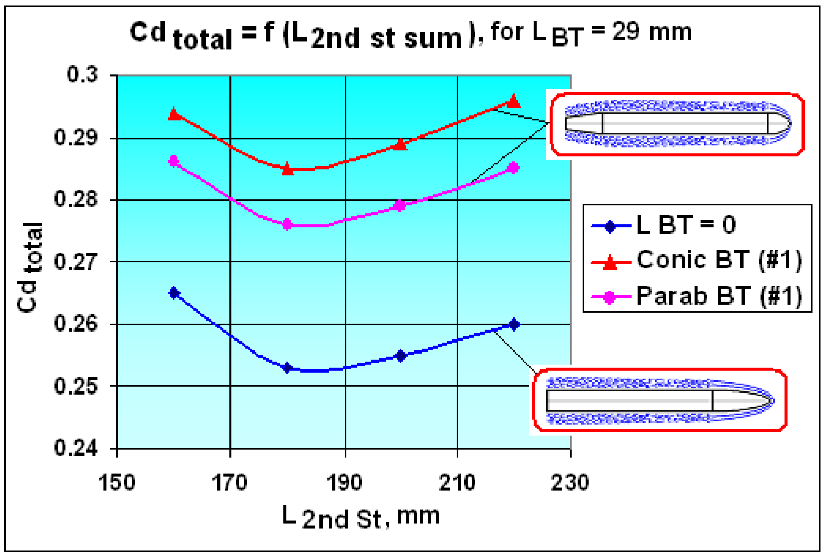
1.3.1. Length of the 2nd stage

Predominantly
Laminar flow cases:

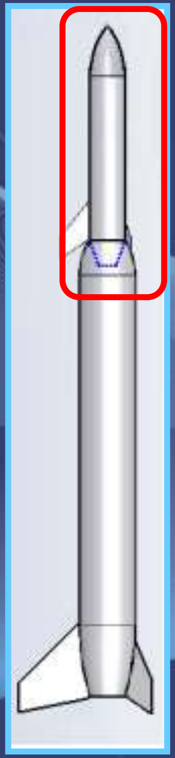




Predominantly
Turbulent flow cases:



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



Conclusions:

1. **In the cases of predominantly Laminar flow: the longer 2nd stage (within reasonable length range) the lower the Cd value.**

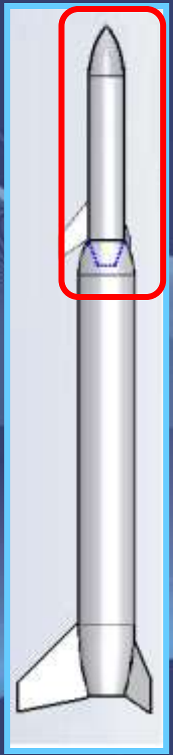
2. **In the cases of predominantly Turbulent flow: there is the optimal 2nd stage length (about 180 mm).**

SEE NOTE

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

Conclusions (con't):

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).



Results for 2nd stage total length of L $_{sum}$ = 180 mm:

For predominantly **Laminar flow :**

	x t	Cd fric	Cd NC	Cd BT	Cd BS	Cd fins	Cd tot
No BT	1	0.047	-0.005	0	0.137	0.031	0.208
Parab BT	0.845	0.079	0.009	0.027	0.056	0.031	0.202
Conic BT	0.861	0.075	0.01	0.059	0.024	0.031	0.199

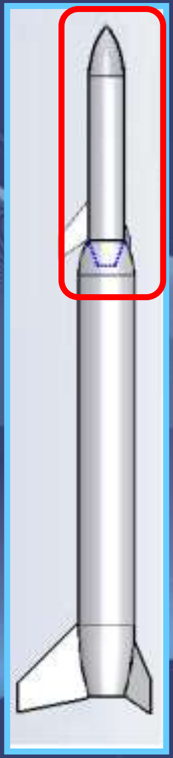
SEE NOTE

Conclusions (con't):

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):

Results for 2nd stage total length of L_{sum} = 180 mm:



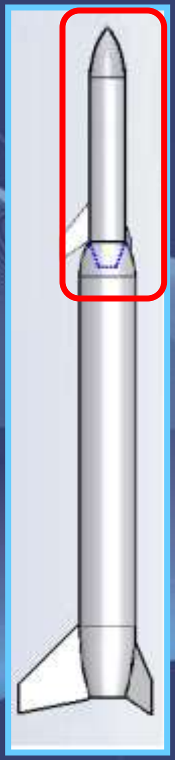
For predominantly **Turbulent flow :**

	x t	Cd fric	Cd NC	Cd BT	Cd BS	Cd fins	Cd tot
No BT	0.146	0.152	-0.005	0	0.074	0.031	0.253
Parab BT	0.055	0.17	0.009	0.027	0.038	0.031	0.276
Conic BT	0.051	0.169	0.01	0.059	0.016	0.031	0.285

SEE NOTE

1.3.1. Length of the 2nd stage (con't 4)

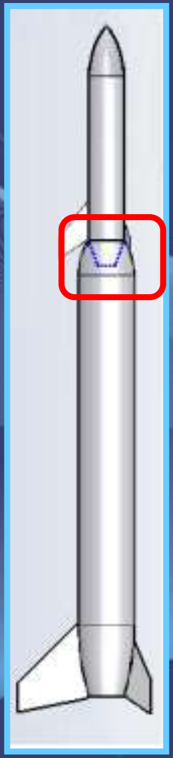
Conclusions (con't):

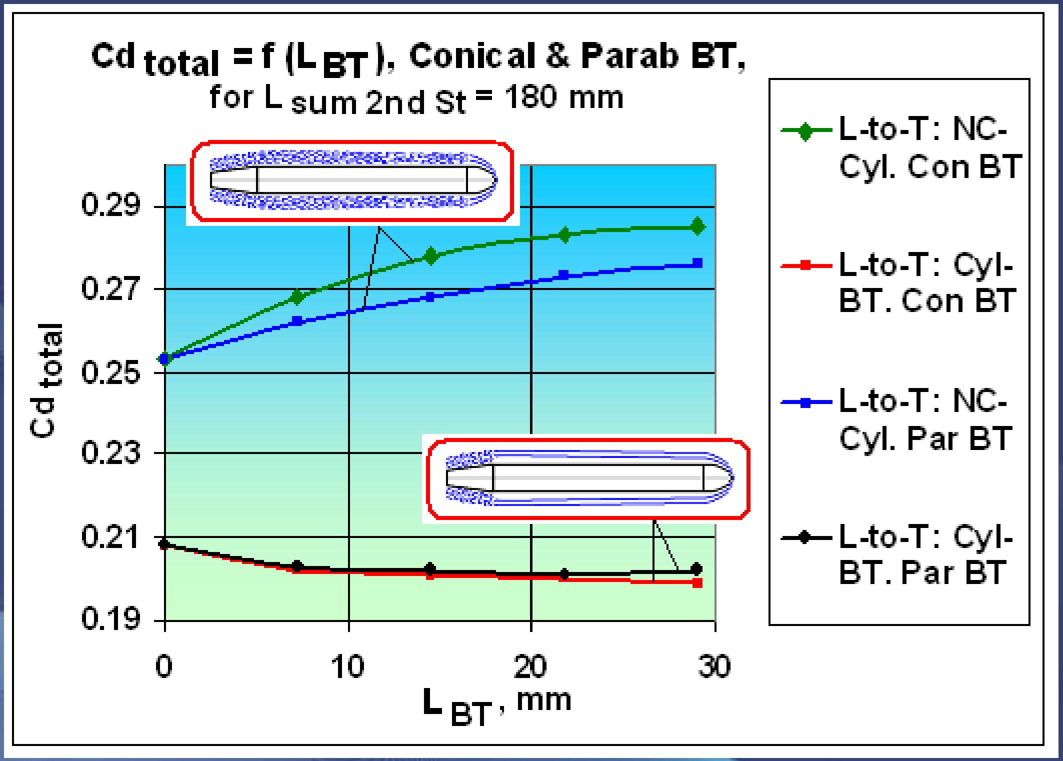


5. For predominantly **Laminar flow**:
The 2nd stage with parabolic BT has a greater Cd_{total} value than the stage with conical BT. However, the difference is very small - about 1 %.

For predominantly **Turbulent flow**:
The 2nd stage with parabolic BT has a lower Cd_{total} value than the stage with conical BT, approximately 3 % lower.

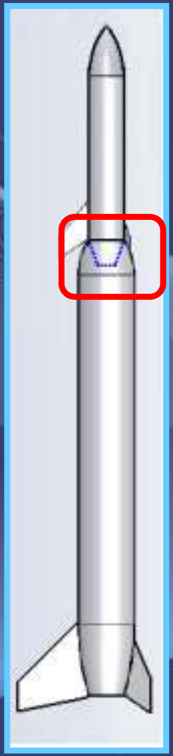
1.3.2. Length of the 2nd stage BT





SEE NOTE

1.3.2. Length of 2nd stage BT (Con’t)



Conclusion:

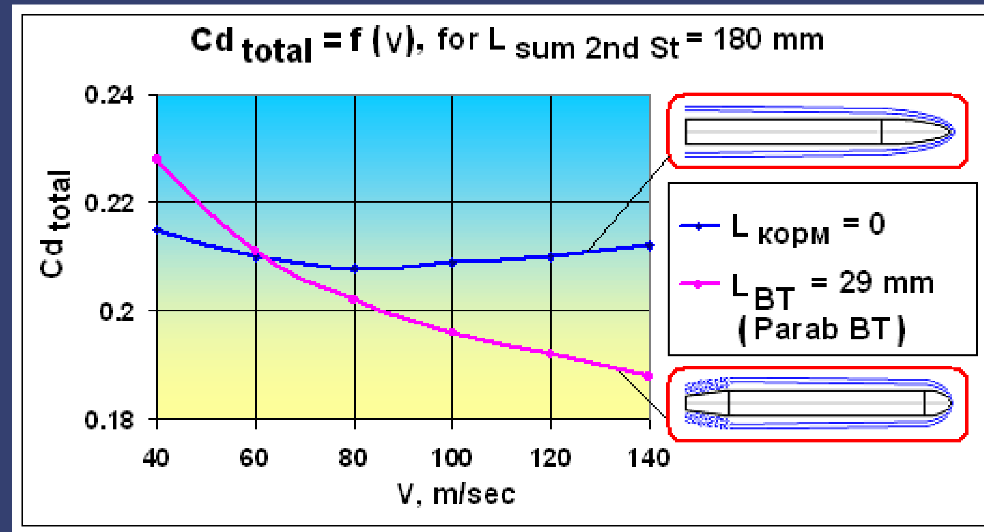
1. The question about «BT-No BT» is transferred into a question about flow type on a cylindrical part of the 2nd stage.

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

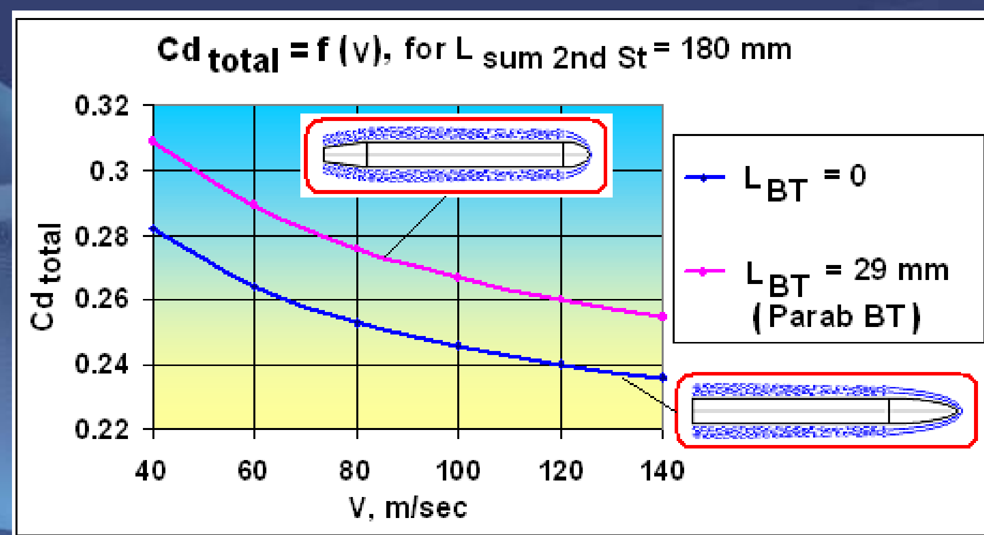
SEE NOTE

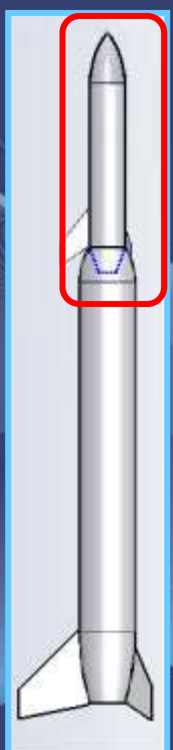
1.3.3. Cd_{total} of 2^{nd} stage vs. flight velocity. X_t (V)=const

Predominantly
Laminar flow cases:



Predominantly
Turbulent flow cases:



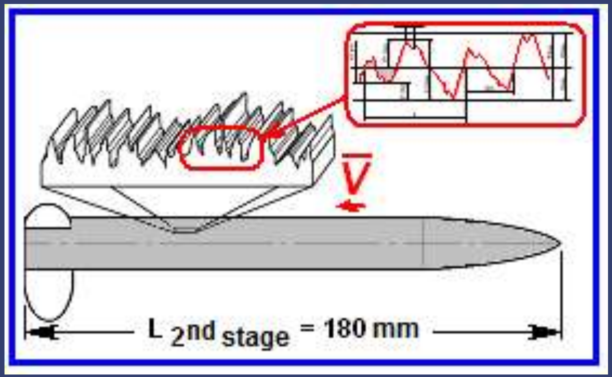


CM. NOTE

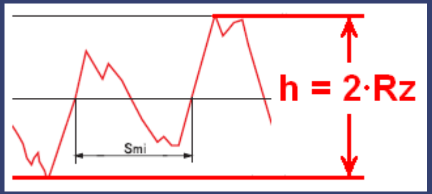
1.3.4. Cd_{total} of 2nd stage = f(v) for X_t = f(V). Impact of a surface roughness

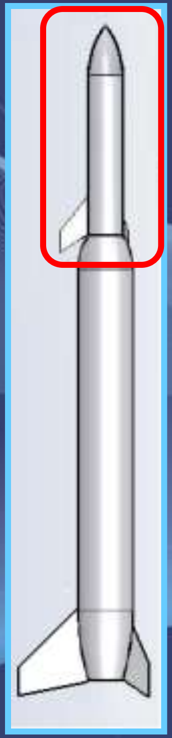
Case under consideration for

numerical analysis:



Assumption:





Heights of roughness peaks under consideration:

1. h = 0.5 μm:

11th grade of finish. **Rz = 0.25 μm**
(from the range of Rz = 0.4 - 0.2 μm)

2. h = 10 μm:

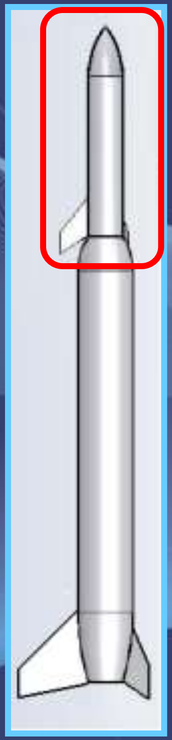
7th grade of finish. **Rz = 5 μm**
(from the range of Rz = 6.3 - 3.2 μm (Ra = 1.25 - 0.63))

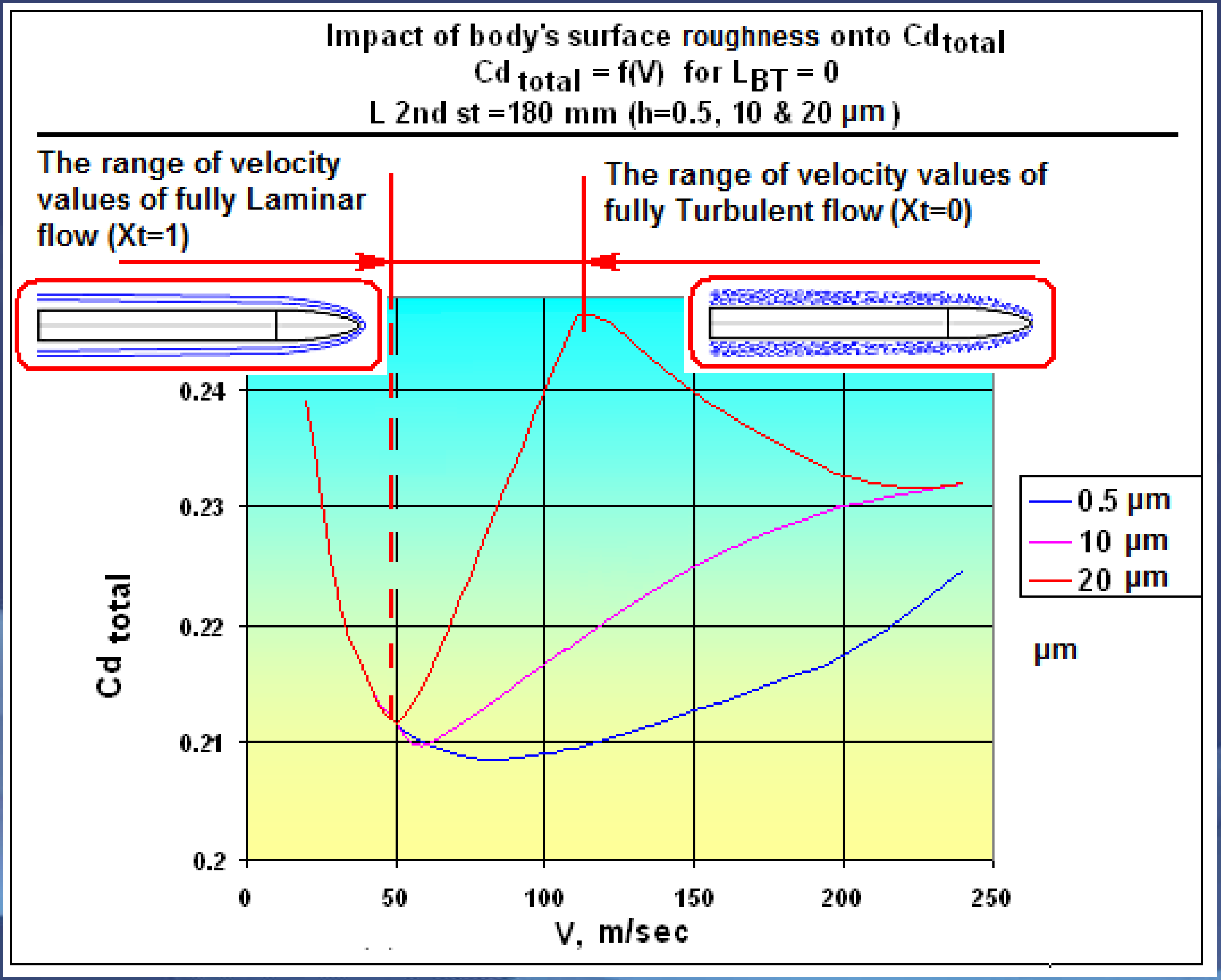
3. h = 20 μm:

6th grade of finish. **Rz = 10 μm**
(from the range of Rz = 10 - 6.3 μm (Ra = 2.5-1.25))

SEE NOTE

1.3.4.1. Results of numerical analysis





1.3.4.2. Results review

1. Height of roughness peaks h = 20 μm:

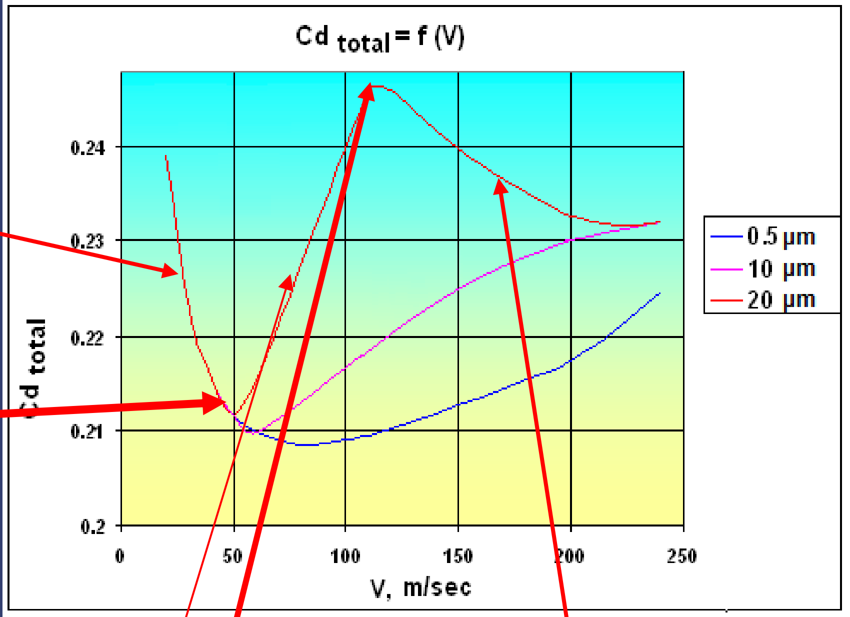
A. For low V - fully Laminar flow:
$Re < Re_t$, $X_t = 1$

$V \uparrow \Rightarrow Re \uparrow \Rightarrow Cd_{fric} \downarrow \Rightarrow Cd_{total} \downarrow$

B. For $V \approx V_{crit}$ ($Re \approx Re_t$) ($X_t \approx 1^{(-)}$)

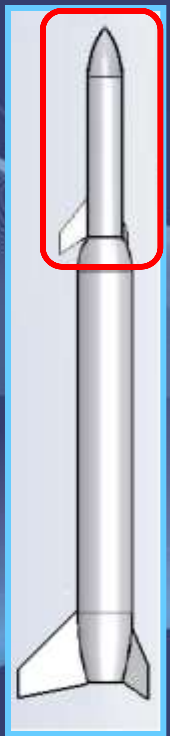
$V \uparrow \Rightarrow Re \uparrow \Rightarrow X_t \downarrow \Rightarrow Cd_{fric} \uparrow \Rightarrow Cd_{total} \uparrow$

The minimum is occurred at the **$Cd_{total} = f(V)$** graph
i.e. ∂ **Cd_{total} (V) / ∂V = 0** for **$Re \approx Re_t$**



C. For $V > V_{crit}$ ($Re > Re_t$) (1> X_t >0)

$V \uparrow \Rightarrow Re \uparrow \Rightarrow X_t \downarrow \Rightarrow Cd_{fric} \uparrow \Rightarrow Cd_{total} \uparrow$



D. For Re_t=0 (X_t =0) - fully Turbulent flow:
$V \uparrow \Rightarrow Re \uparrow \Rightarrow Cd_{fric} \downarrow \Rightarrow Cd_{total} \downarrow$

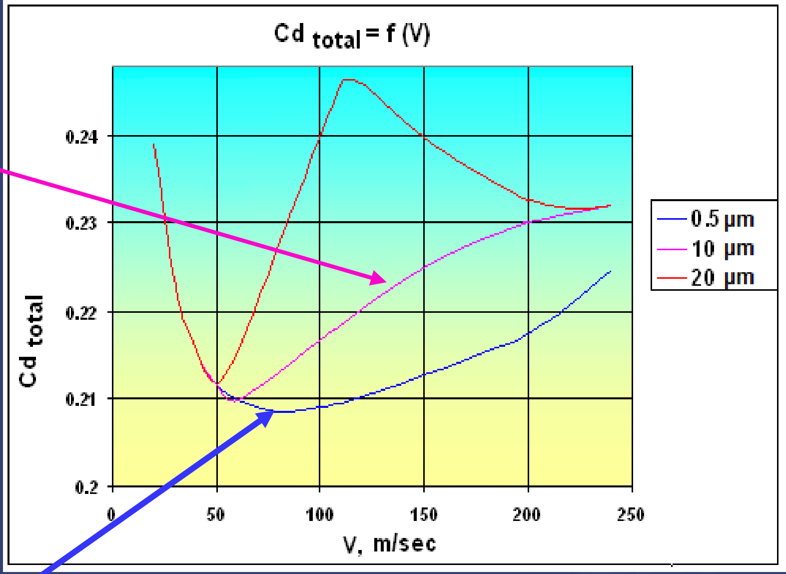
The maximum is occurred at the **$Cd_{total} = f(V)$** graph
i.e. ∂ **Cd_{total} (V) / ∂V = 0** for **$X_t = 0$**

E. Fully Turbulent flow for **$Re > Re^*$ (Re_t=0, X_t =0):**

$V \uparrow \Rightarrow Re \uparrow \Rightarrow Cd_{fric} \downarrow \Rightarrow Cd_{total} \downarrow$

SEE NOTE

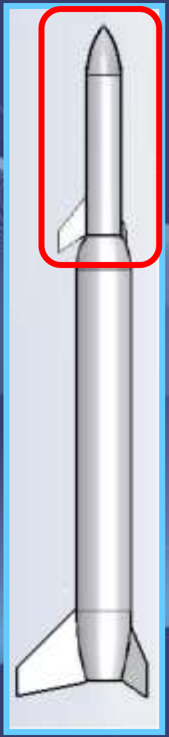
1.3.4.2. Results review (con't 1)



2. Height of roughness peaks h = 10 μm:

Qualitatively **Cd_{total} (V)** plot for **h = 10 μm** is similar to **Cd_{total} (V)** plot for **h = 20 μm**.

However, **X_t =0** only at **V=240 m/sec**



3. Height of roughness peaks h = 0.5 μm:

Fully Laminar flow (X_t =1) **for the entire range of** V = 20 … 240 m/sec

However:

$$\left.\begin{array}{l} V\uparrow \Rightarrow Re\uparrow \Rightarrow Cd_{fric}\downarrow \\ \qquad\qquad\qquad\qquad \Downarrow \\ \qquad\qquad\qquad\quad Cd_{BS}\uparrow\uparrow \end{array}\right\} \Rightarrow Cd_{total}\uparrow$$

The minimum is occurred at the **Cd_{total} =f(V)** graph, i.e. **$\partial Cd_{total}(V) / \partial V = 0$** at some **V**

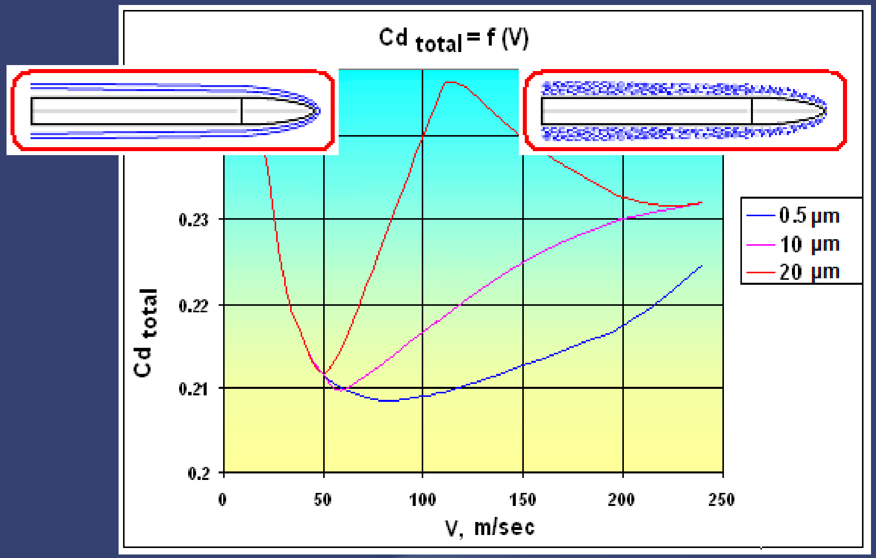
SEE NOTE

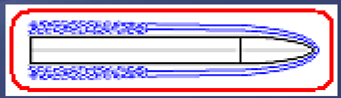
1.3.4.2. Results review (con't 2)

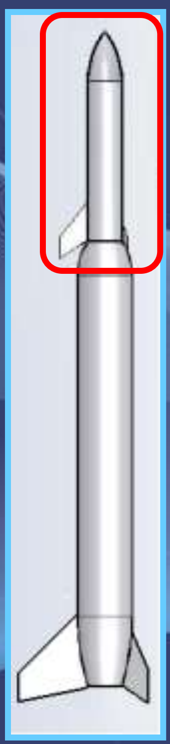
General comments

1. 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.







$Cd_{total}(h_2) = Cd_{total}(h_1)$

2. For **$1 > X_t > 0$:**

Lesser surface roughness results in:

1. **$V_{crit}(h_2) > V_{crit}(h_1)$**

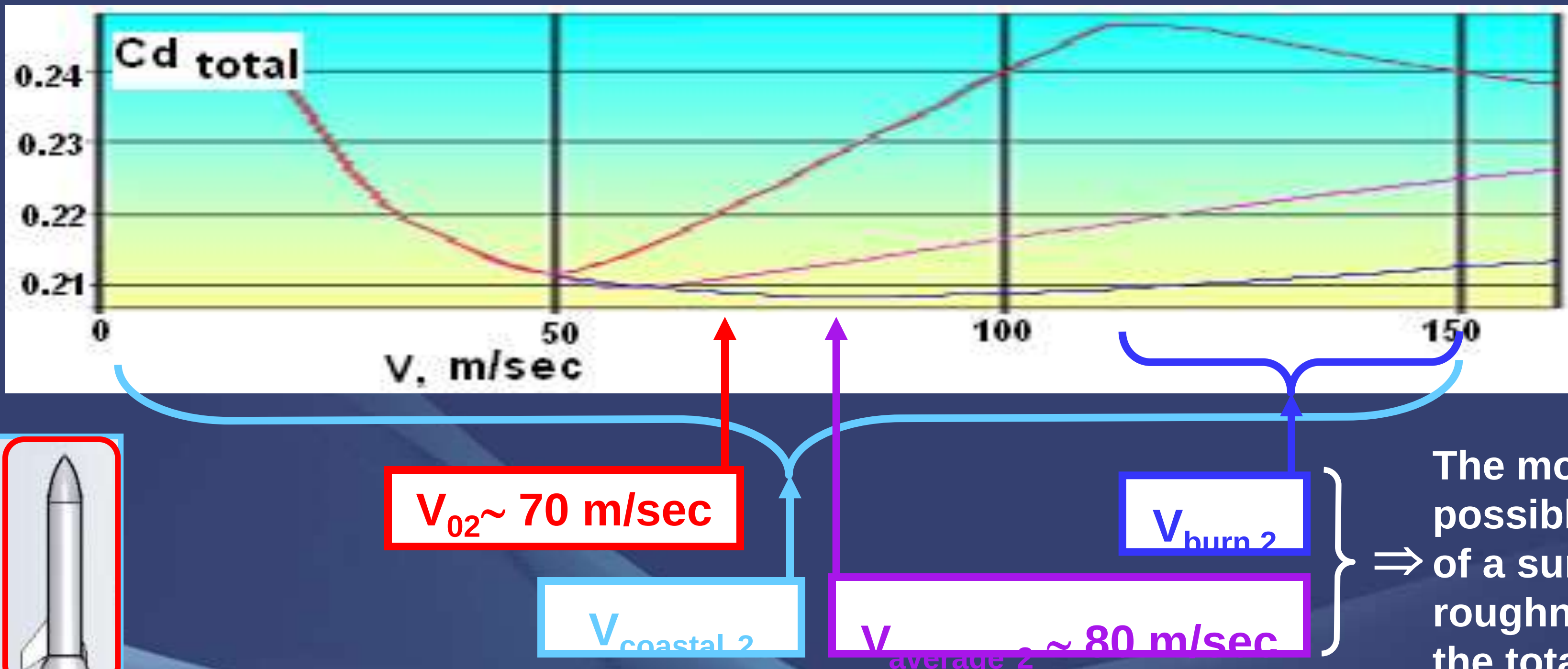
2. Velocity range for which **1> Xt >0** is widened

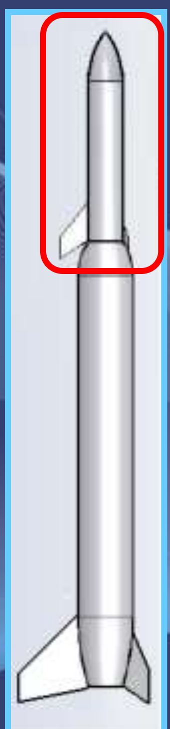
3. ∂ **Cd_{total} (V) / ∂V $|_{h=h_2}$ < ∂ Cd_{total} (V) / ∂V $|_{h=h_1}$**

SEE NOTE

1.3.4.2. Results review (con't 3)

3. For velocities **50 … 150 m/sec (**in the range of **Rz = 0.25** µm **… 10** µm**)**:





The most possible impact of a surface roughness onto the total flight altitude H_Σ

$\Rightarrow$

Δ Cd_{total} (h = 0.5 µm and 20 µm) ≈ 15 % for **V = 100 …140 m/sec**

⇓

Δ $Cd_{average\int}$ (h = 0.5 µm and 20 µm) ≈ 10 %

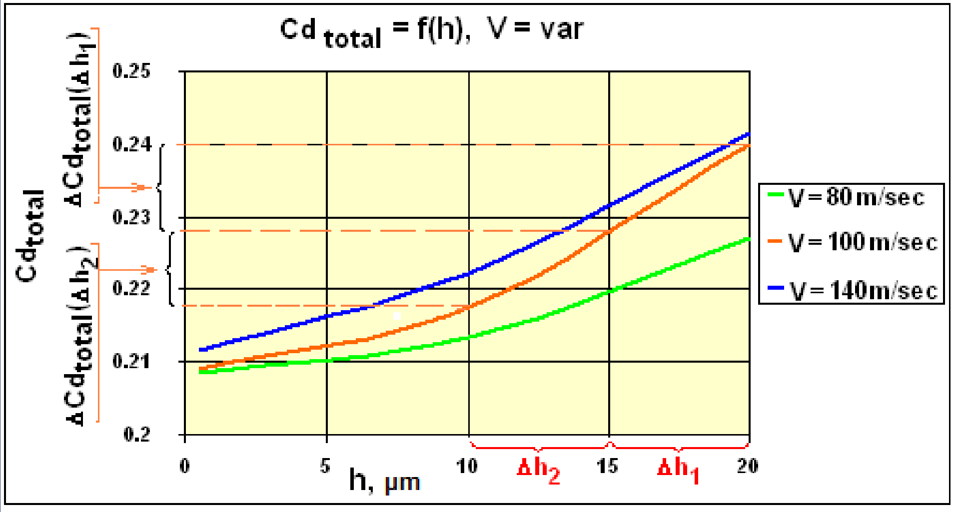
⇓

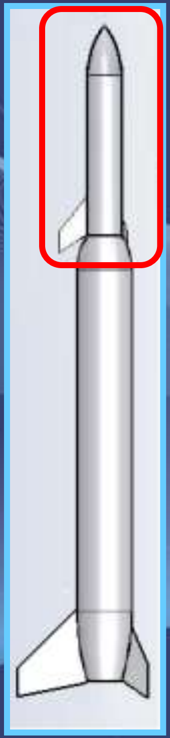
$\Delta H_\Sigma \approx$ 6 %

SEE NOTE

1.3.4.2. Results review (con't 4)

4. A progressive increace of Cd_{total} with surface roughness h





$$\partial^2 Cd_{total}(h) / \partial h^2 > 0$$

I.e. each subsequent equal decreasing of the surface roughness value corresponds to a lesser decreasing of Cd_{total}.

Each subsequent equal decreasing of **Cd_{total}** may be achieved by increasingly higher cost.

$$\text{For } \Delta h_2 = \Delta h_1$$

$$\Downarrow$$

$$Cd_{total}(\Delta h_2) < \Delta Cd_{total}(\Delta h_1)$$

$$\Downarrow$$

$$\Delta H_\Sigma(\Delta h_2) < \Delta H_\Sigma(\Delta h_1)$$

SEE NOTE

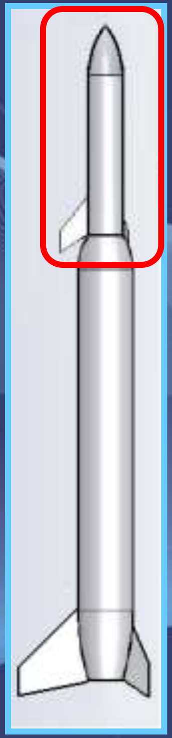
1.3.4.2. Results review (con't 5)

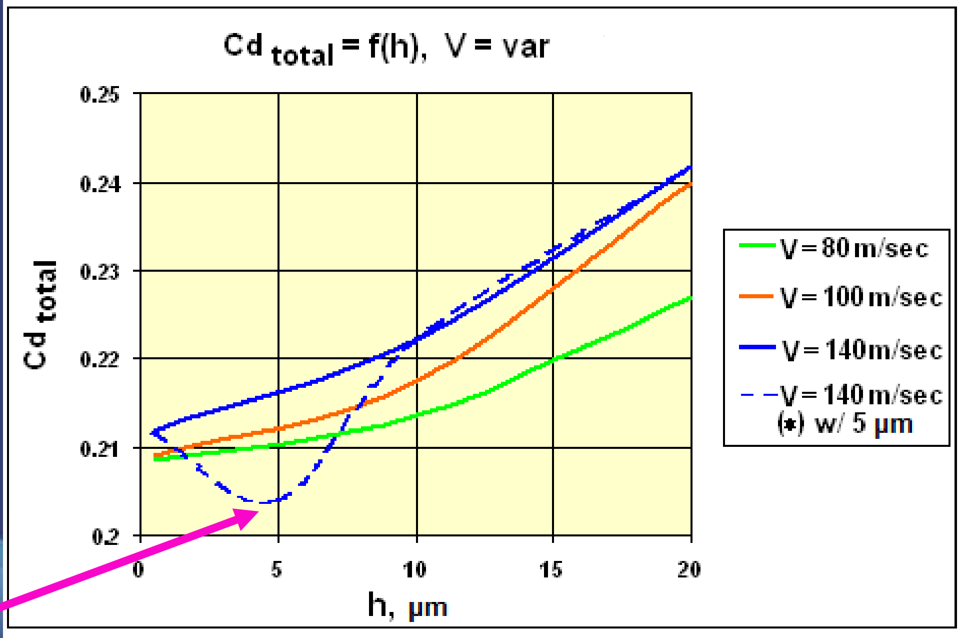
5. Paradox of an existence of the $Cd_{total}(h)$ curve minimum

For fully laminar flow and $\mathbf{V \approx V_{crit}}$

$\mathbf{Cd_{BS} = 2 \ldots 3\ Cd_{fric}} \Rightarrow$ significant impact of $\mathbf{Cd_{BS}}$ onto $\mathbf{Cd_{total}}$

$$\left.\begin{array}{c} h \downarrow \Rightarrow Cd_{fric} \downarrow \\ \Downarrow \\ h \downarrow \Rightarrow Cd_{BS} \uparrow\uparrow \end{array}\right\} \Rightarrow Cd_{total} \uparrow$$





The minimum is occurred at the $\mathbf{Cd_{total}}$ **=f(h)** graph, i.e. ∂ $\mathbf{Cd_{total}}$ **(h) / ∂h = 0)** for $\mathbf{V \approx V_{crit}}$ (+)

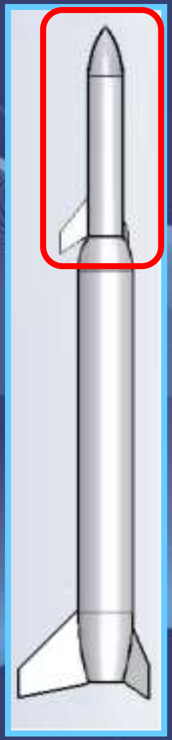
DESIGN and **FABRICATION** approaches combining **min** $\mathbf{Cd_{fric}}$ (at **min h**) and **min** $\mathbf{Cd_{BS}}$ is necessary

SEE NOTE

1.3.4.3. Practical conclusions

1. Make the external surface as smooth as possible

(with the lowest surface rougness).



2. Take into a consideration the type of the dependence $Cd_{total}(V)$

while selecting engines parameters (burn time) for 2nd stages.

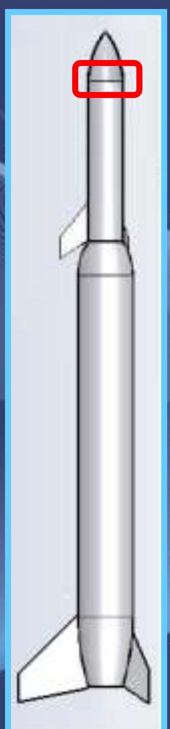
SEE NOTE

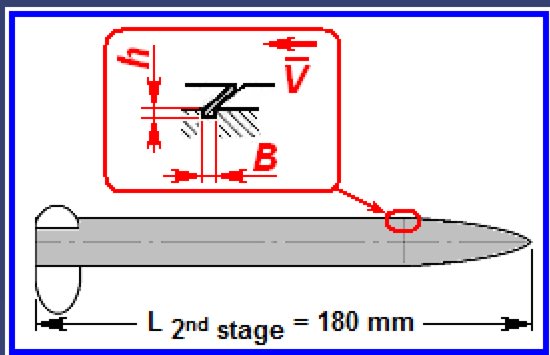
1.3.5. Cd_{total} of 2nd stage = f(v) for X_t = f(V). Impact of the body-NC juncture groove dimensions

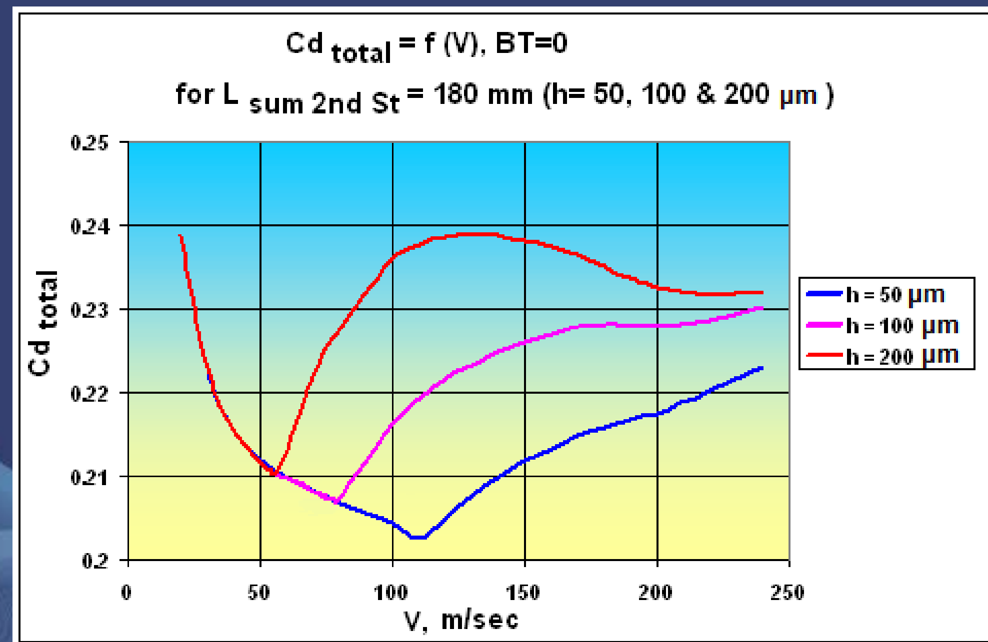
The case under consideration:

Assumption: **h / B = 0.5**

Results of numerical analysis:





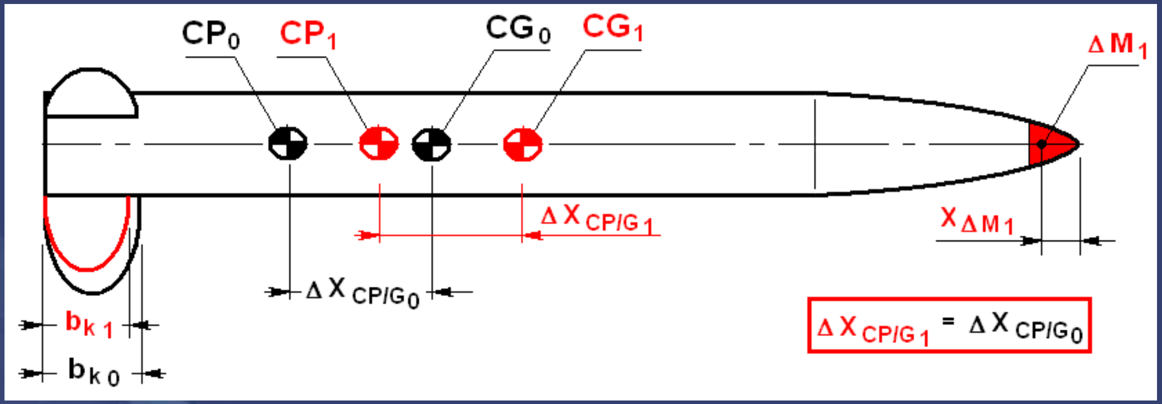


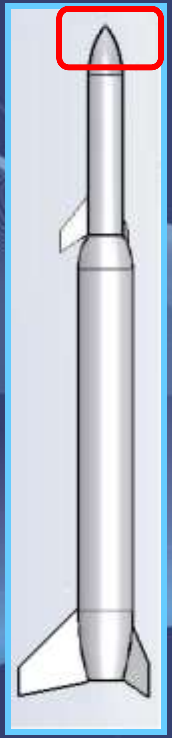
Practical conclusions:

Avoid presence of grooves / notches on the external surface or make them minimal

SEE NOTE

1.3.6. NC-loading effect onto Cd_{total}



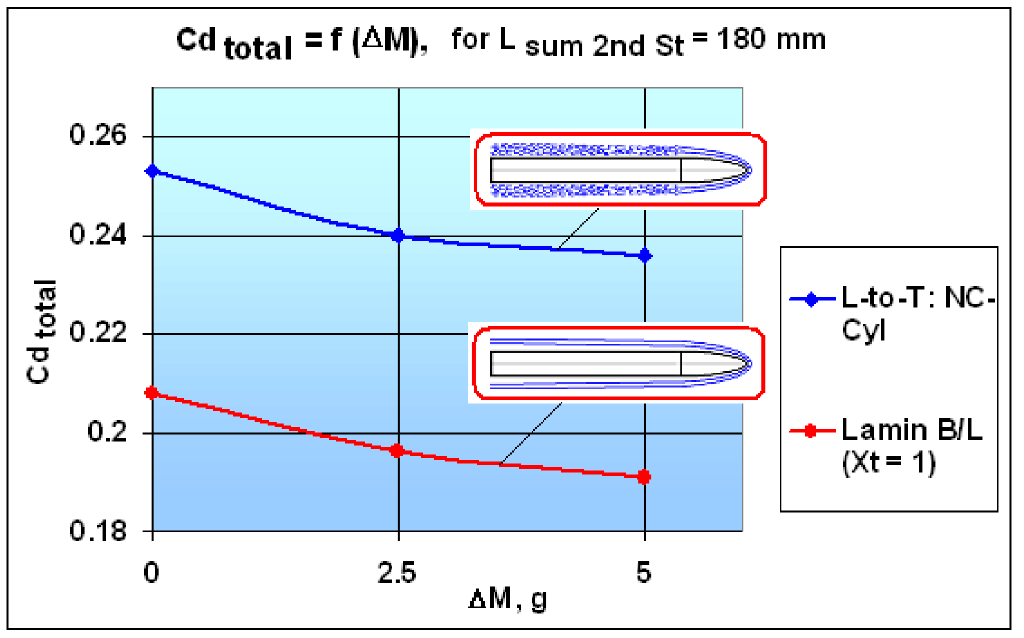


$\Delta M \uparrow$ □⇒ Position of CG move forward ⇒ $S_{fins} \downarrow$ ⇒ $Cd_{fins} \downarrow$ ⇒ $Cd_{total} \downarrow$

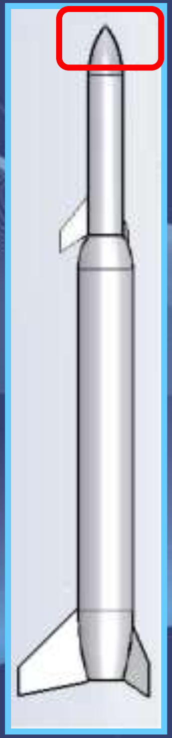
1. $M_{2^{nd}\ Stage}$ (Δ M =0) = 15.4 g

2. NC is loaded with lead, density ρ_{Pb} = 11.34 g/cm^3

1.3.6.1. NC-loading effect onto Cd total. Static case



A loading of the additional 2.5 g into the top of NC decreases Cd_{tot} by 5.1% and 5.8% for Turbulent and Laminar flow respectively.



The rule of thumb:

$$(\partial H / H) / (\partial Cd / Cd) \approx (-0.6)\text{-}(-0.7)$$

Appl for S3/6/9

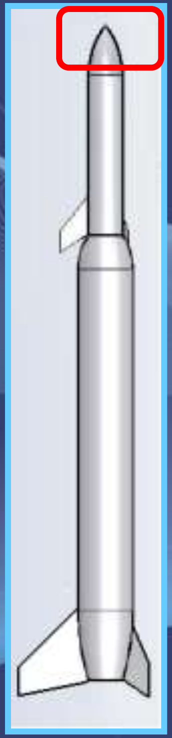
And a 5% of the Cd decrease will "bring" at least an additional 3% in the flight altitude.

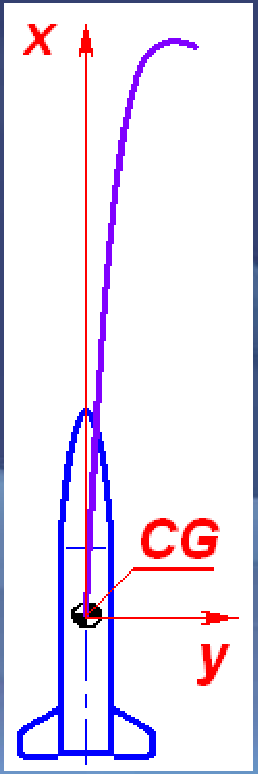
SEE NOTE

1.3.6.2. NC-loading effect onto Cd $_{total}$. Dynamic effect

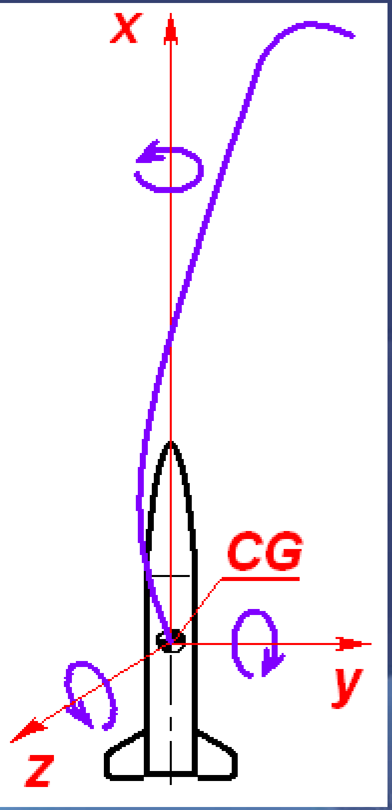
Simplified approach

of Model's motion





Model's motion in reality

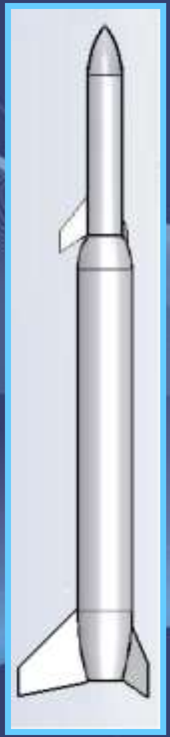


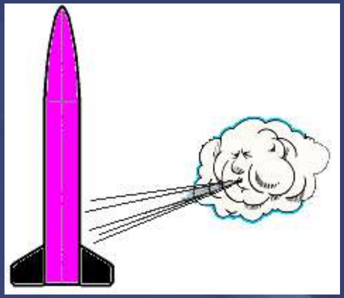
SEE NOTE

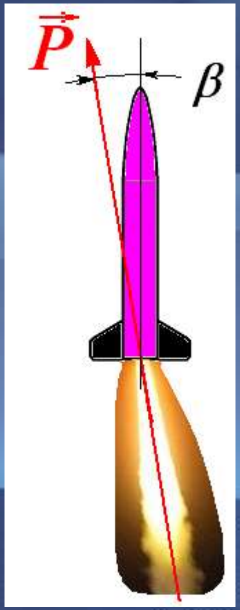
1.3.6.2. NC-loading effect onto Cd $_{total}$. Dynamic effect (Con't 1)

Model's Motion under disturbances

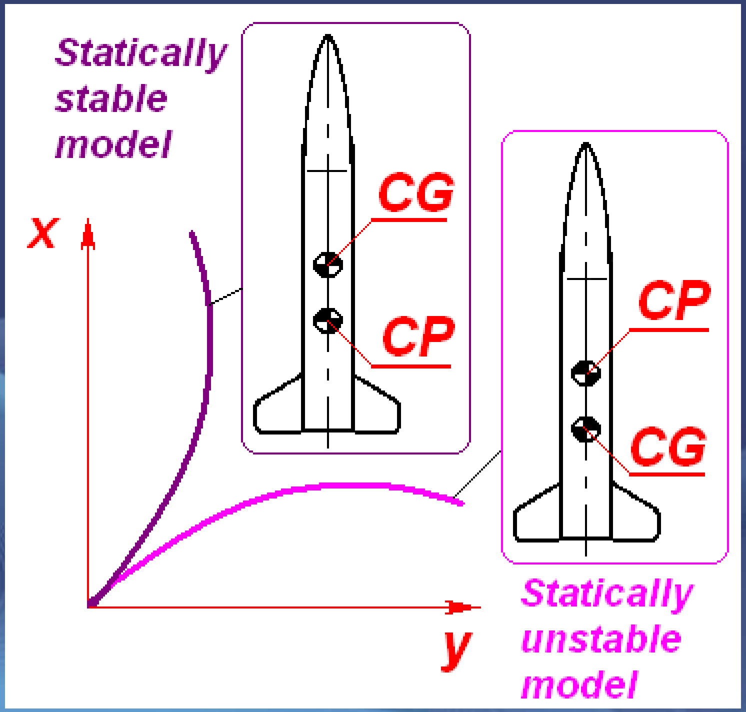
Model's flight disturbances:







Deviation from trajectory under disturbances for statically stable and unstable models



SEE NOTE

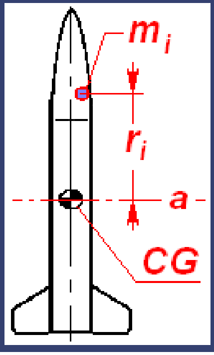
1.3.6.2. NC-loading effect onto Cd_{total}. Dynamic effect (Con't 2)

Measure of the inertia (at the rotation) - Moment of inertia with respect to a specific rotation axis J_a

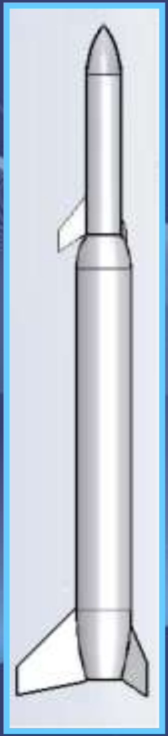
$$J_a = \sum_{i=1}^{n} m_i r_i^2$$

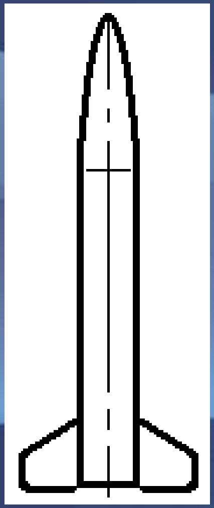
m_i — mass of an i-particle,

r_i — perpendicular distance from the axis **a** of rotation to an i-particle



Model without additional load



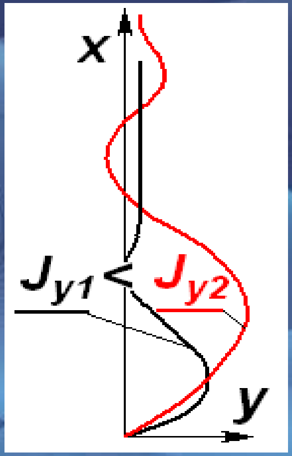


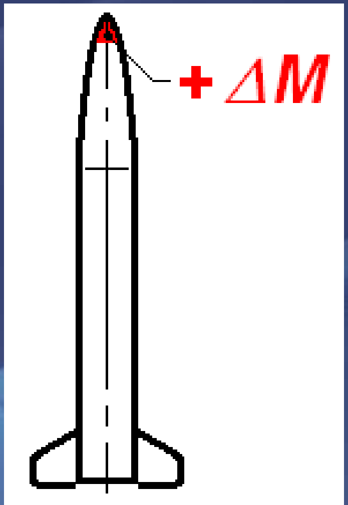
Model with additional load ΔM

Longitudinal moment of inertia J_y :

$$J_{y1} < J_{y2}$$

Aproxinate view of trajectories for models with various J_y values under disturbance – disturbance's rejection:





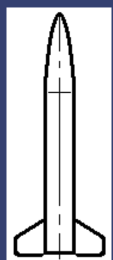
SEE NOTE

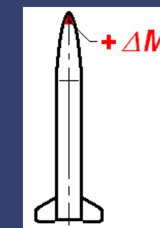
1.3.6.2. NC-loading effect onto Cd $_{total}$. Dynamic effect (Con't 3)

Model without additional load

$J_{y1} < J_{y2}$

Model with additional load ΔM



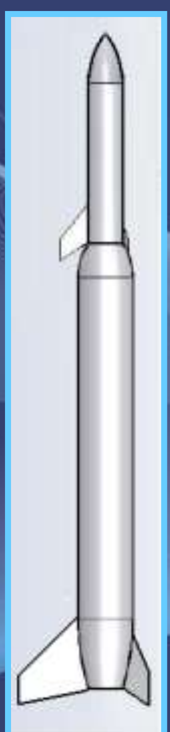


Model's angle of rotation **ΔΘ** :

$\Delta\Theta_1 > \Delta\Theta_2$

Angle-of-attack α_{max}:

$\alpha_1 > \alpha_2$



However:

Disturbance rejection time interval τ_{rej}:

$\tau_{rej\ 1} < \tau_{rej\ 2}$

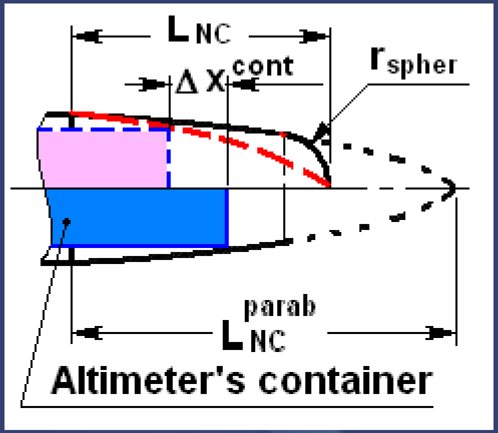
Average-integral value of $Cd_{total\ \int}$ during disturbance – disturbance's rejection:

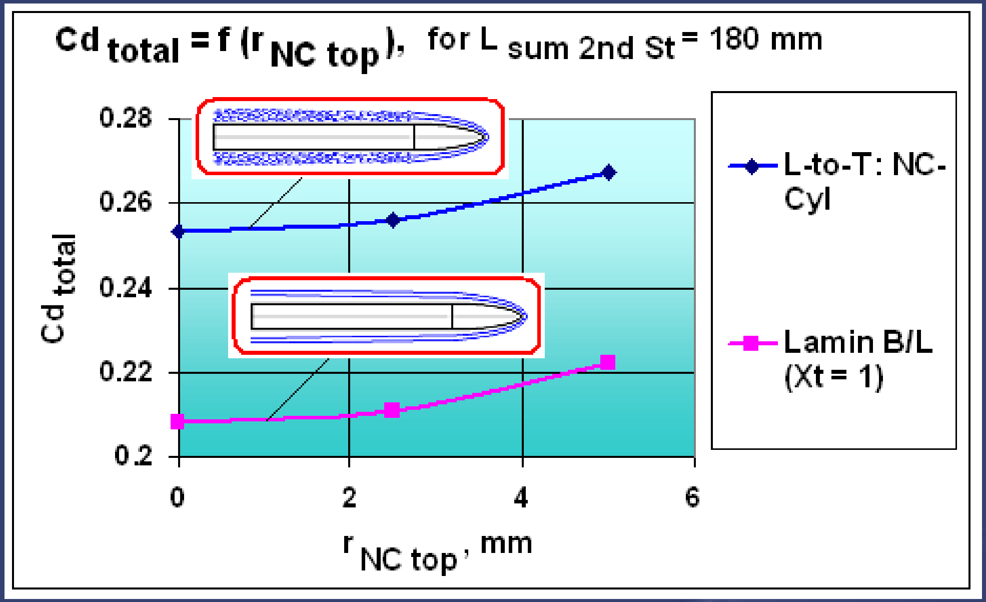
$$Cd_{total\ \int}(\tau_{\Sigma\ 1}) < Cx_{total\ \int}(\tau_{\Sigma\ 2})$$

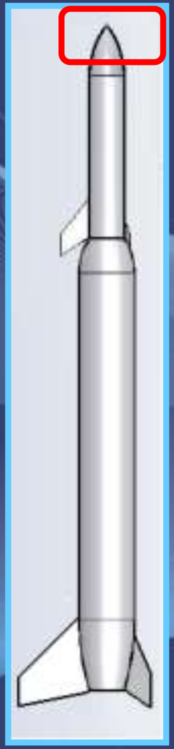
Therefore: ΔM - ? TBD

SEE NOTE

1.3.7. NC-top-rounding effect onto Cd total







Larger R $_{NC\ top}$ will allow moving forward altimeter and battery ⇒

⇒ Position of CG move forward ⇒ S $_{fins}$ ↓ ⇒ Cd $_{fins}$ ↓.

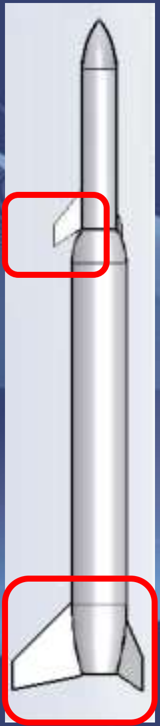
However, larger R $_{NC\ top}$ ⇒ Cd $_{NC}$ ↑ and (ΔCd $_{NC}$ + ΔCd $_{fins}$) >0 ⇒ Cd $_{total}$ ↑.

Conclusion:

Keep the shape of NC totally parabolic. Just round the very top of it (with a radius about r = 0.1 - 0.2 mm) in order to avoid nonsymmetrical jamming during handling and landing.

SEE NOTE

1.3.8. Fins dimension



Whatever method is used to determine a model's stability (Barrowman equations or some software like Rocksim or...), and whatever criterion is chosen as the stability margin in order to determine fins' total area, some adjustment (fins area enlargement) should be done in order to take into account the dynamic factors, to compensate the unknown factors and different misalignments (see the par. 2. of the current PPP). Some of these factors can be under control of a modeler, and others are out of control, for example, the engine's thrust fluctuations.
Did you ever watch engine's static tests?
You can see a slight fluctuation in the direction of the exhaust

gases backflow.

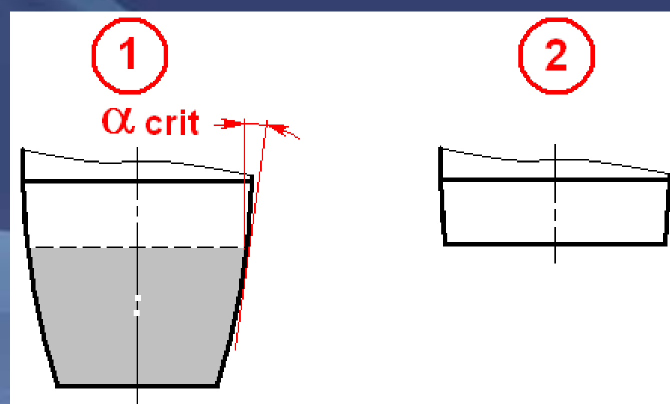
1.4. 1st stage geometry selection

1.4.1. Aft cone length / pitch cone angle

Boat tail cone half-angle (for conical shape) or local tangent angle (for parabolic shape) should not exceed critical level (α crit = 7.5°).

"FDoM"

Otherwise a flow separation will take place.

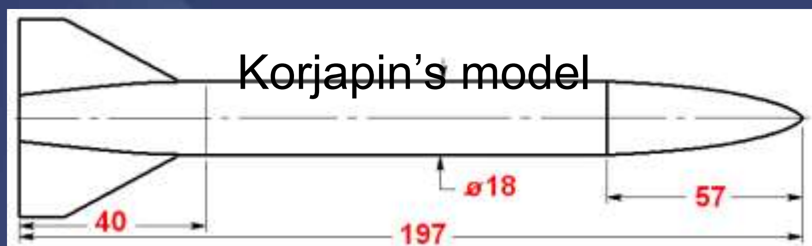


Cd base (model 1) ≈ Cd base (model 2)

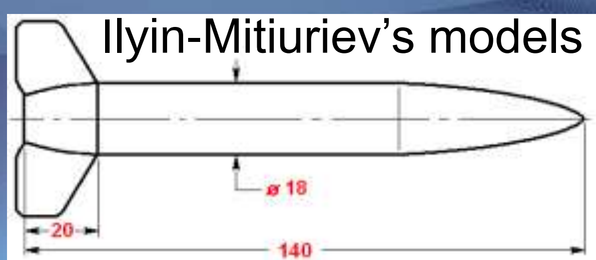
That is not just a theory and text-books recommendations, but proof from personal experience.

Results of 6th WSMC-1985, Bulgaria

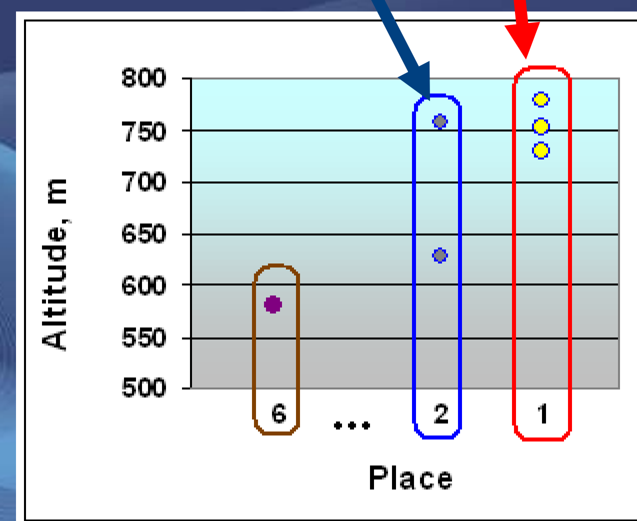
Podium S1A (L-R):
ILYIN Sergei (USSR) – 2nd
KORIAPIN Alexey (USSR) – 1st
BARBER Trip (USA) – 3rd …
… (MITIURIEV A. (USSR) - 6th)



Traditional front ejection system



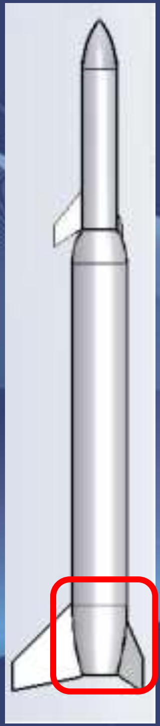
Rear ejection system

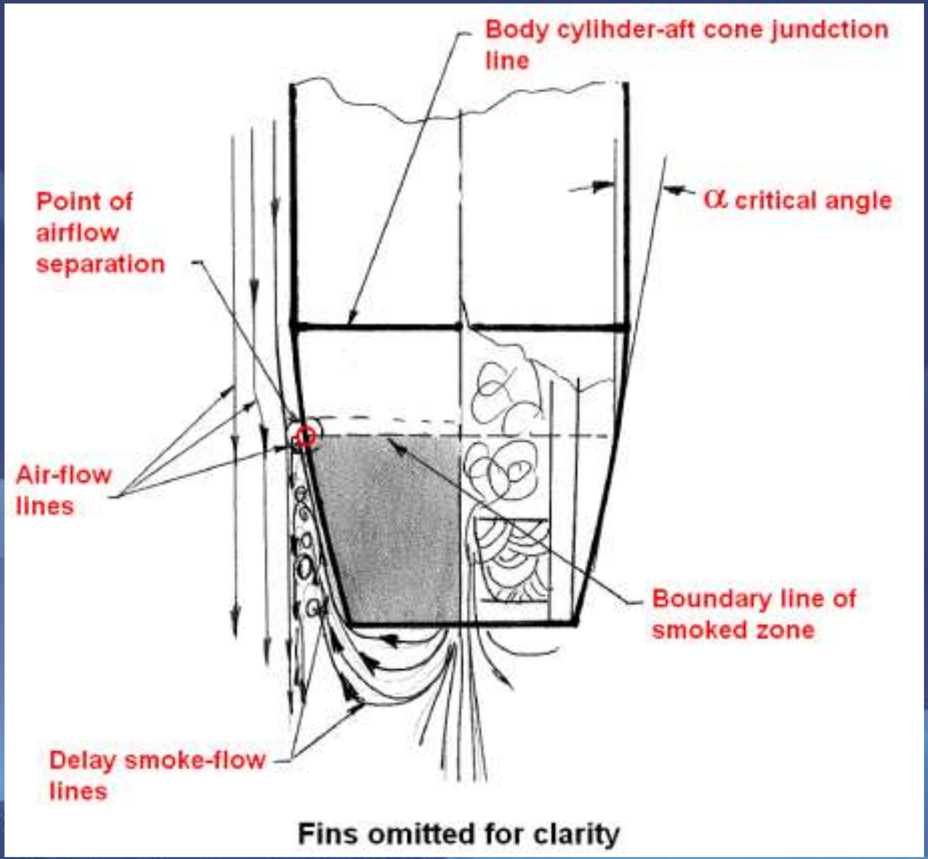


SEE NOTE

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

Ilyin-Mitiuriev's models Post-flight look (boat tail w/ black coating) and flow reconstruction.



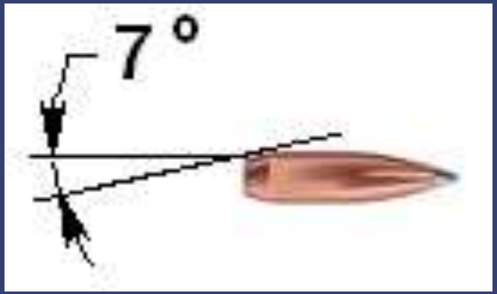


SEE NOTE

Recommendations for BT

1. In order to have a safety margin:

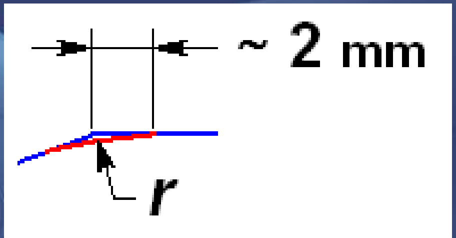
Bullet's BT pitch cone angle:



$$\alpha_{con\ BT} = \alpha_{max\ par\ BT} = 7°$$

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



Appl for S3/6/9

However, It will increase BT length (the body length with a diameter < 40 mm).

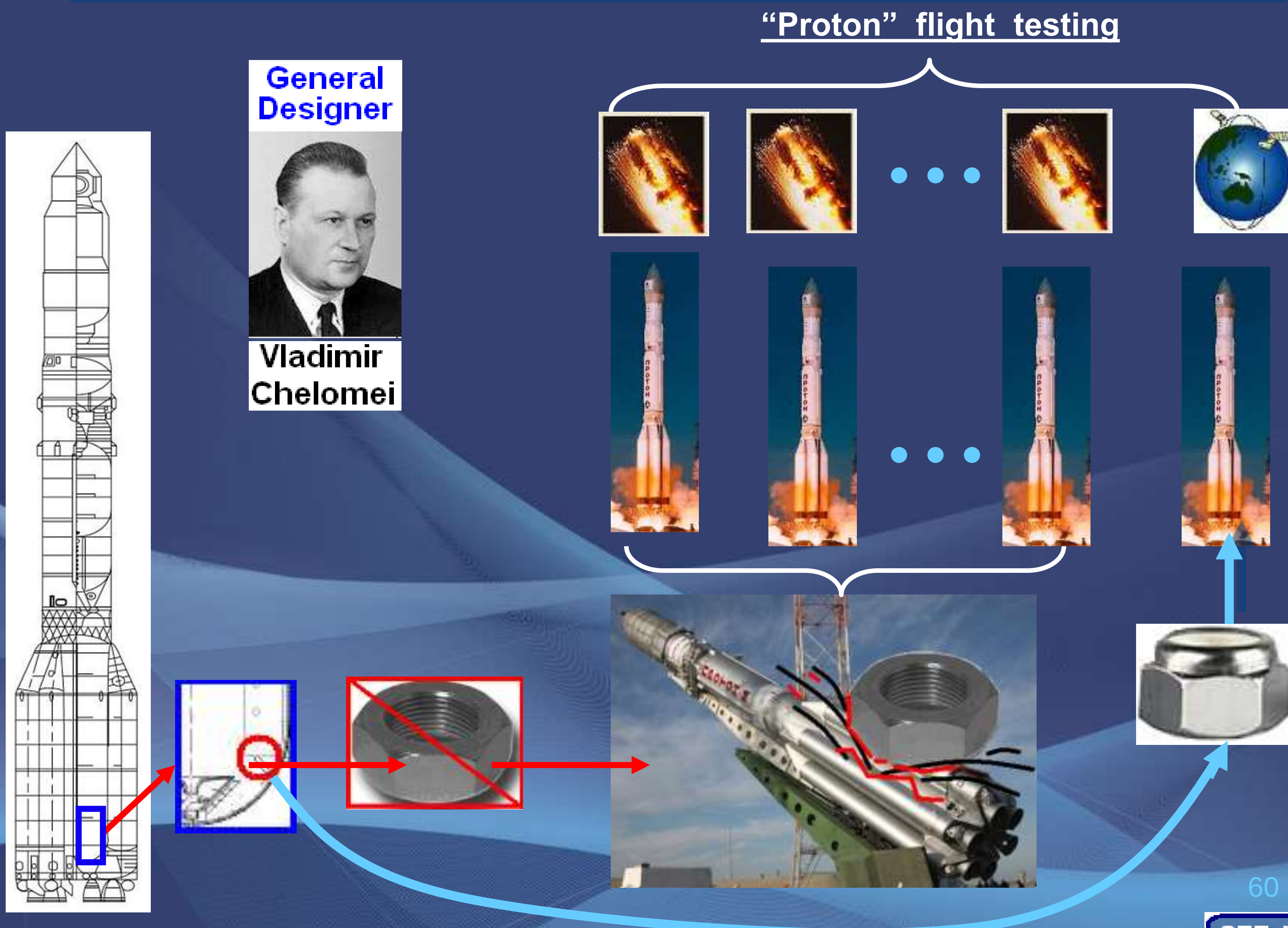
SEE NOTE

”lyrical digression”

“THERE ARE NO TRIFLES IN THE AEROSPACE INDUSTRY !”

SEE NOTE

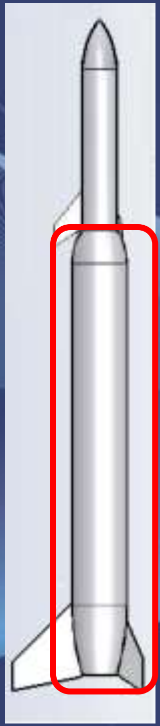
"PROTON" rocket vs. Nut



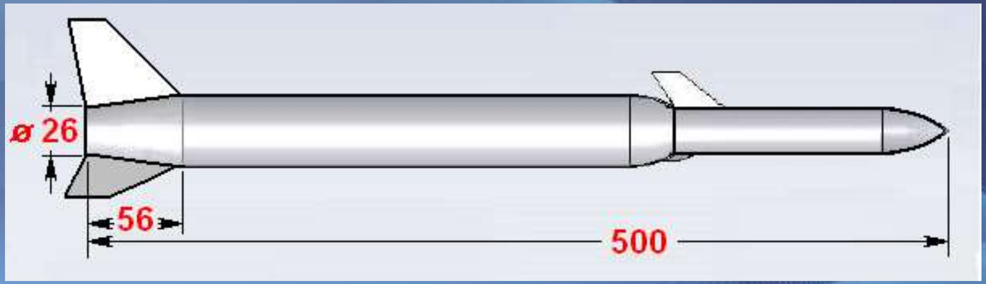
SEE NOTE

1.4.2. Model's total length (1^{st} stage length)

2 models comparison:
L 2nd St = 160 mm in both cases.



#1. L total = 568 mm; Dbase = 18 mm (α = 7°)



#2. L total = 500 mm; Dbase = 26.3 **mm (α = 7°)**

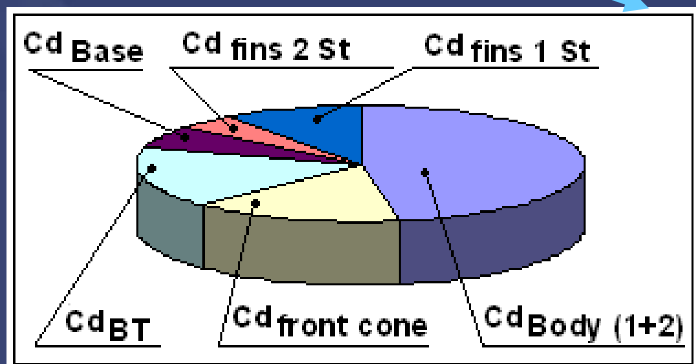
1.4.2. Model's total length (1st stage length) (con't)

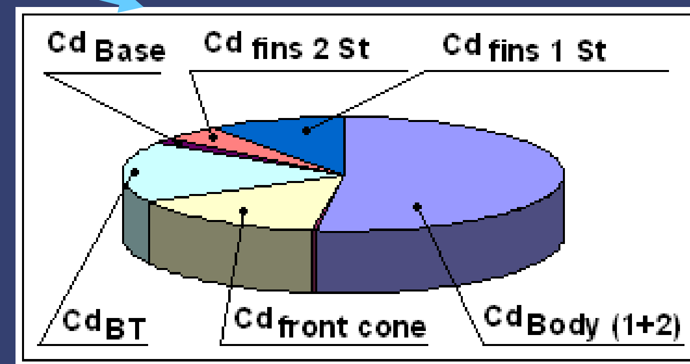
Cd calculated for v = 40m/s $\approx$ V average for 1st stage

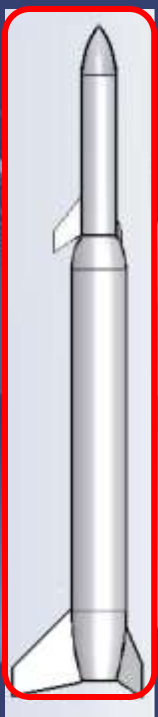
#1 : Cd total = 0.333

#2 : Cd total = 0.327

1st Stage Cd total composition:







Moreover, *∂M0 / ∂L for 1st St body = 1.3 … 2.0 g/dm*

Δ Cd total = - 1.6% and Δ *M0* = - 1 g (or - 3%) $\Rightarrow$
$\Rightarrow$ Δ V burnout 1st St = + 2%

Conclusion:

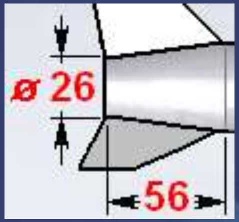
It is not worth to make 1st stage longer in order to decrease BT base diameter.

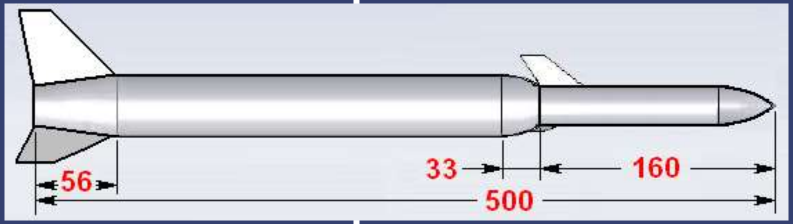
Make model as short as possible (500 mm).

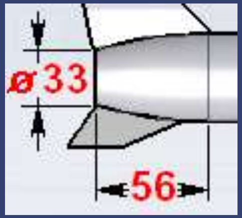
SEE NOTE

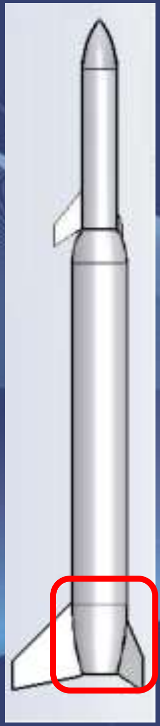
1.4.3. Boat Tail shape

Conical boat tail vs. Parabolic boat tail









#1 : Cd total = 0.327

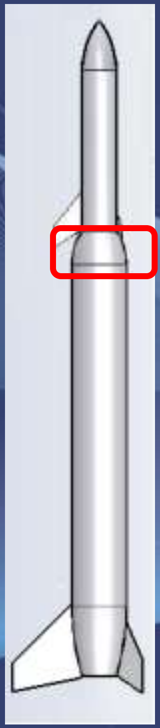
#2 : Cd total = 0.316

~ 3% drop in the value of Cd_{total} despite of 26 % increase in BT base diameter (from 26.3 mm to 33.1 mm) in order to meet limitation $\alpha = 7°$.

Conclusion:

Parabolic shape for BT is better than Conical.

1.4.4. 1^{st} stage Top Transitional Cone



1. Length.

Absence of data (reliable data) on Cd values of transitional (2^{nd}-to-1^{st} stage) cone makes it impossible to perform preliminary analysis on optimal division between lengths of Top Transitional Cone and Boat Tail.
Issue of "Top Transitional Cone length vs. Boat Tail length" is open.

"Top Transitional Cone length vs. Boat Tail length" - ?

2. Shape.

I will recommend Parabolic (not the Conical) shape.
It will have definitely a lower Cd value.

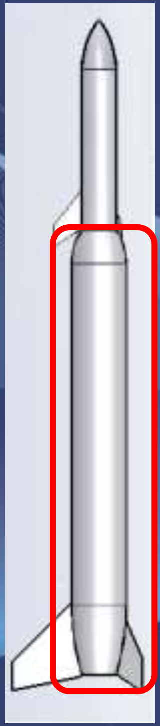
1.4.5. Recommendations

1. Model (and 1st stage) is as short as possible (500 mm).

2. If you have an “extra” length for boat tail, do not exceed critical level of a local tangent angle, $\alpha_{\textbf{crit}} = 7.5°$.

In order to have a safety margin:

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



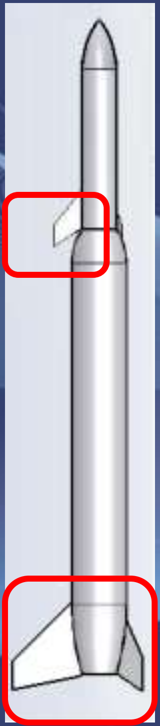
3. Parabolic shape for BT and Transitional Front Cone.

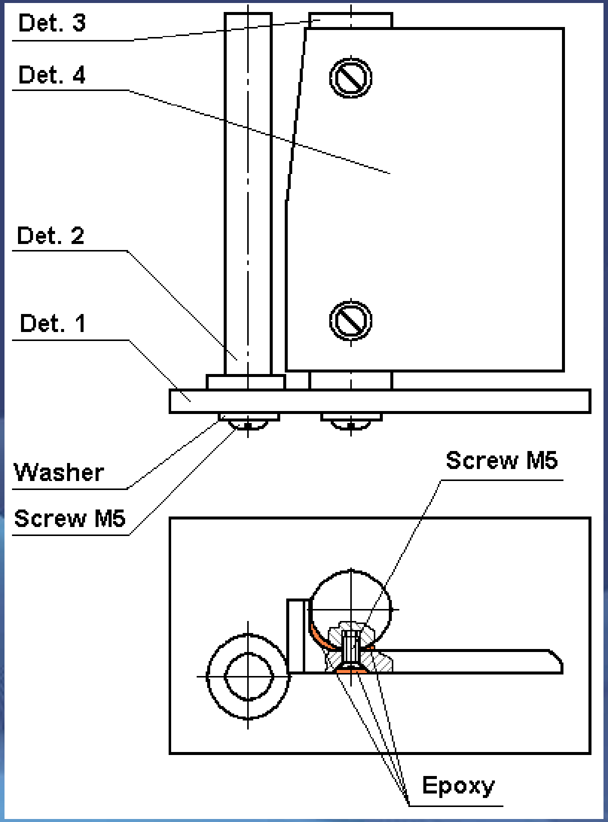
2. Alignment

SEE NOTE

2.1. Fins plane - centerline alignment

- Do not glue fins to body "by eye". Use fin Jig



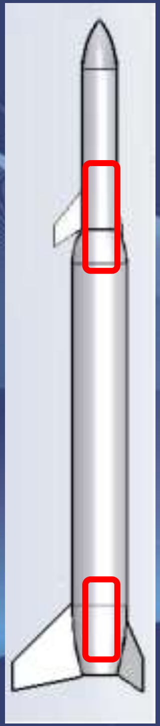


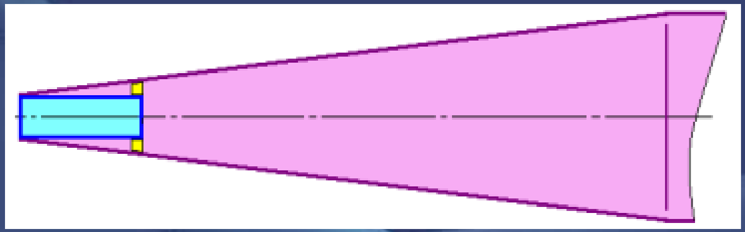
SEE NOTE

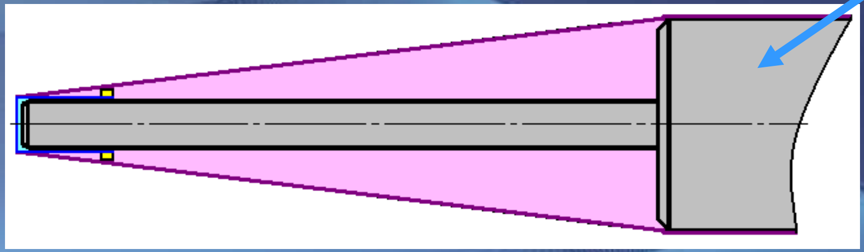
2.2. Thrust vector – centerline alignment (engine mount – centerline alignment)

- Pay attention to engine mount cyllidricity / variations in wall thickness (especially for short tubes).

- For extreme accuracy use special assembly mandrel(s).

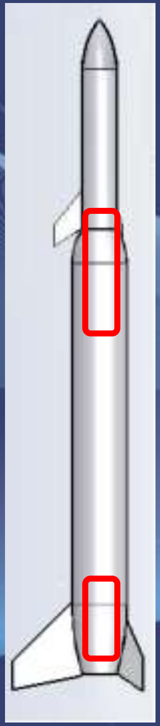


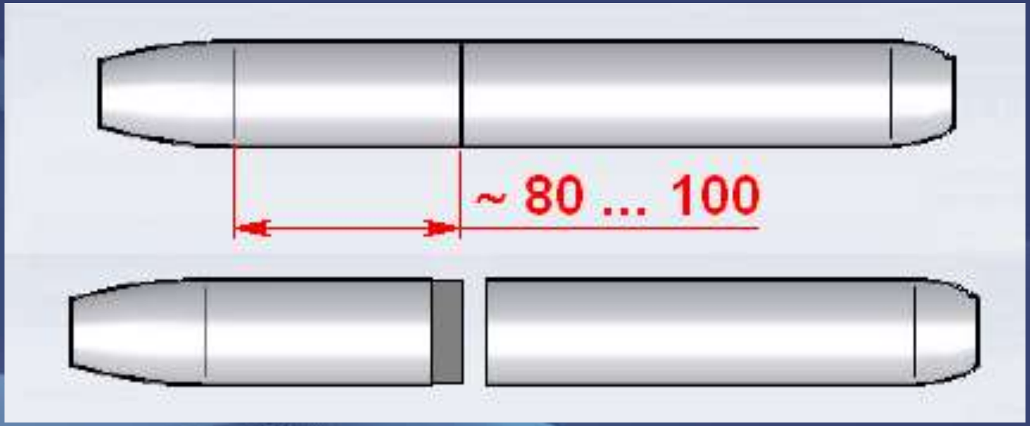




2.2. Thrust vector – centerline alignment (con't)

Recommended juncture point for 1st Stage Body:



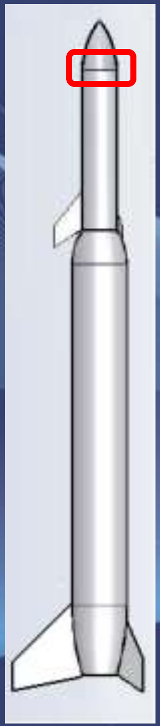


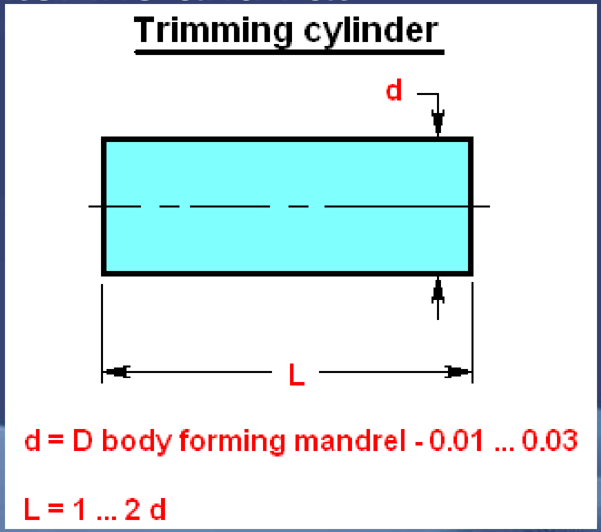
SEE NOTE

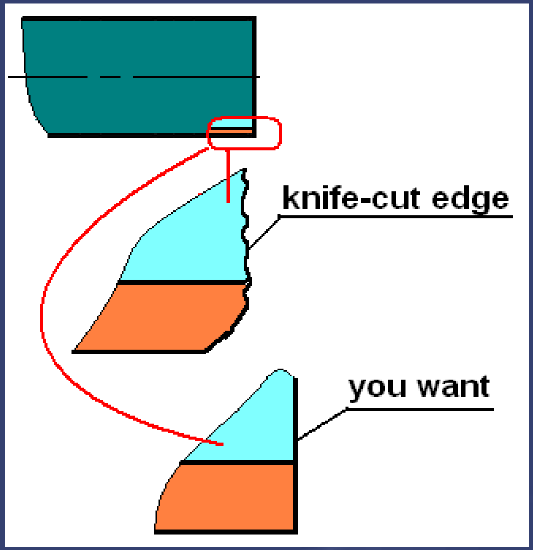
2.3. Body - NC alignment

Use trimming mandrel (cylinder) to cut part's edges.

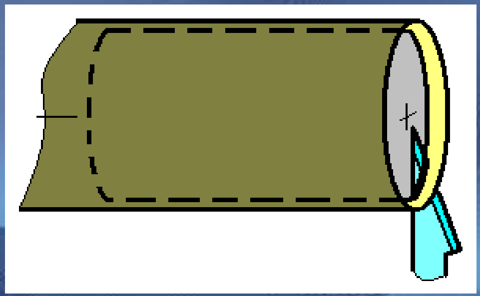
Edges planes are perpendicular to centerline and flat.

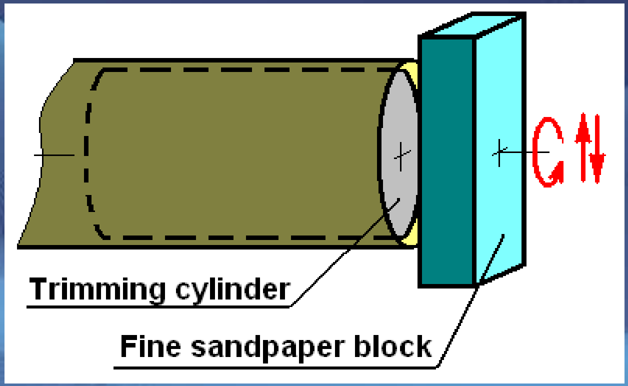






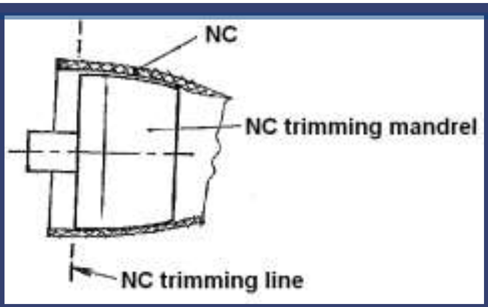
Body tube trimming



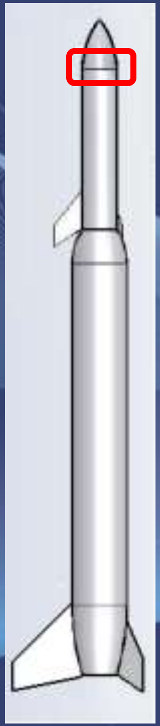


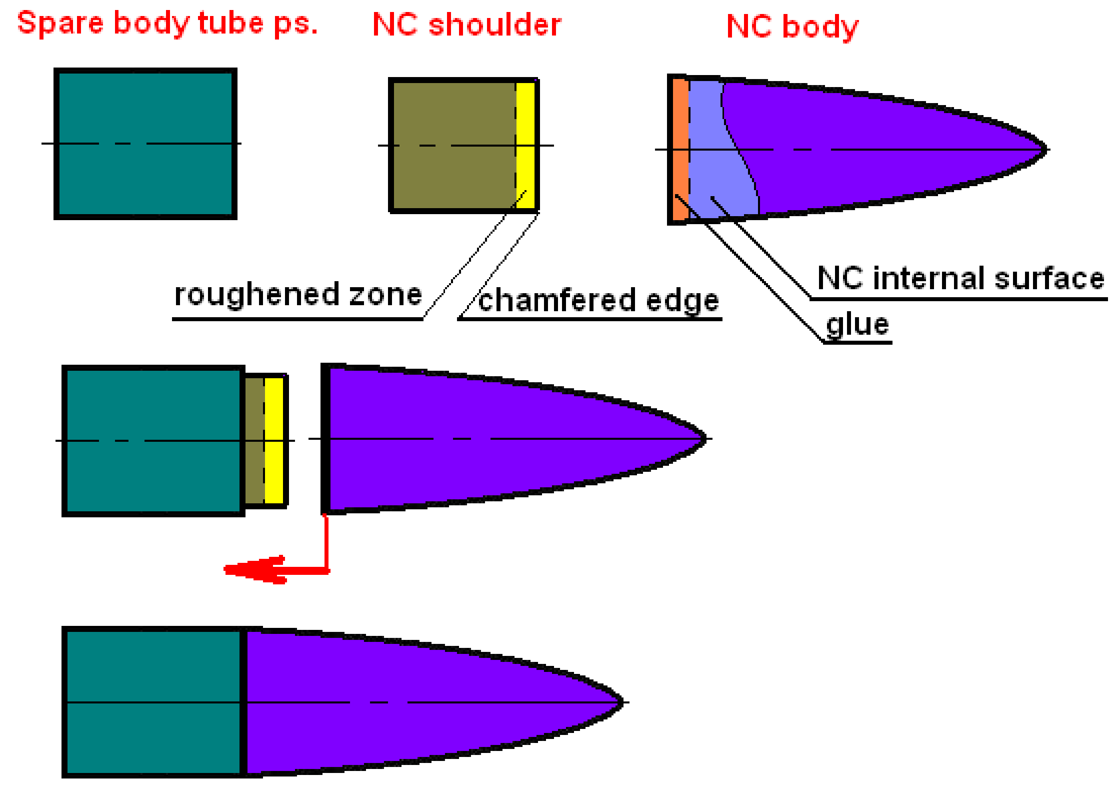
2.3. Body - NC alignment (con't)

NC trimming



NC-NC shoulder assembly





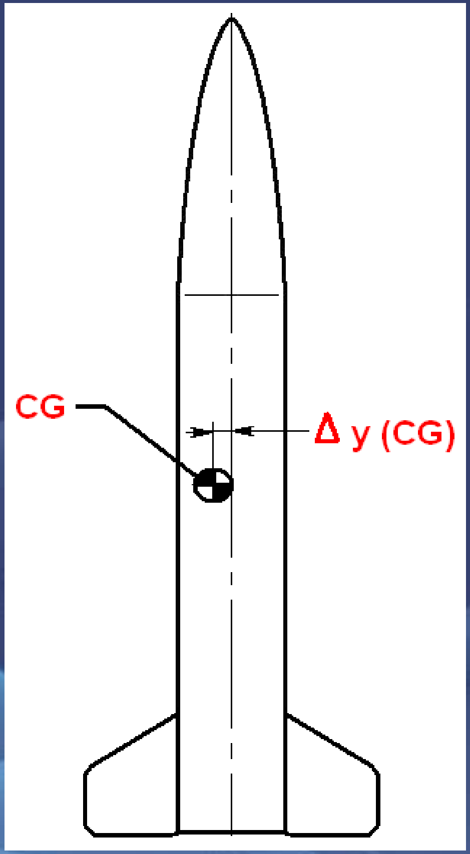
2.4. Mass distribution inside of a model. CG – centerline alignment

Check CG location of altimeter + battery and streamer inside of the body.
Parts should not be loose.

[Δ y (CG) ≠ 0] ⇒

⇒ [α (angle of attack) ≠ 0] ⇒

⇒ [Cd ↑]



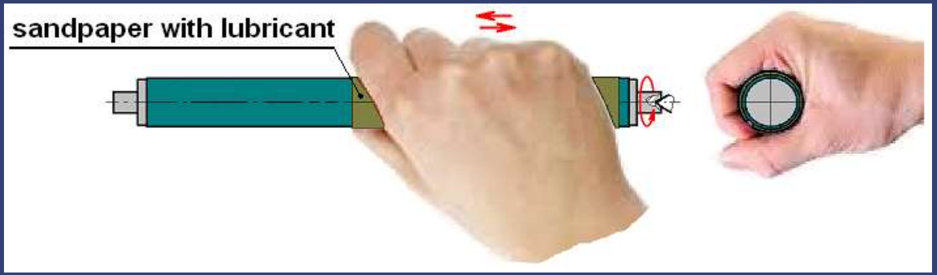
3. 2nd stage drag reduction

3.1. Body's external surface

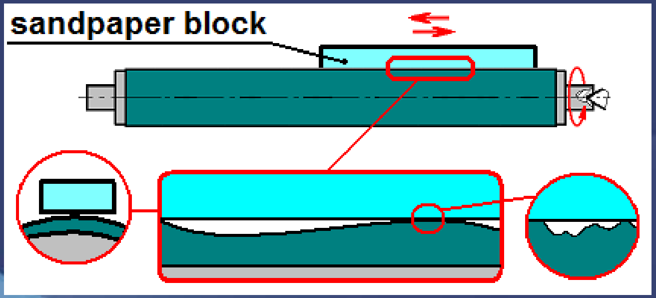
3.1.1. Minimal surface rougness and waviness

Attaining the minimal surface rougness in combination with minimal waviness by turns sanding:

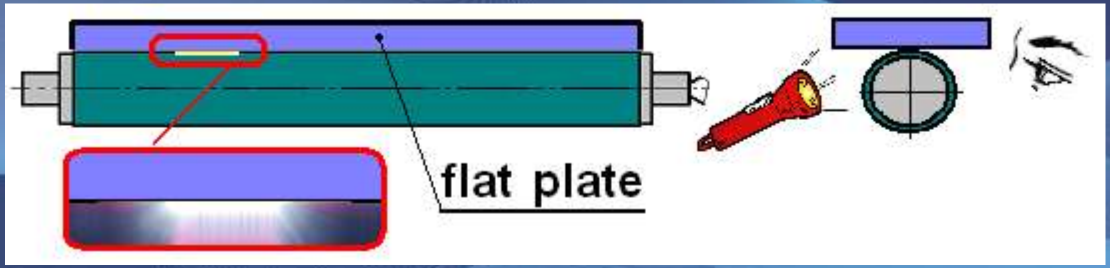
- OVER the SURFACE:



- ALONG the GENERATOR LINE:



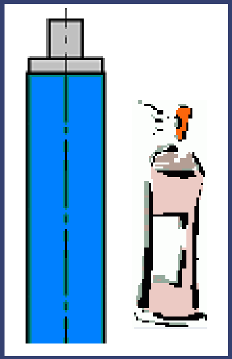
Waviness level checking



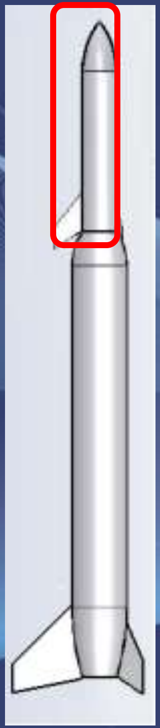
SEE NOTE

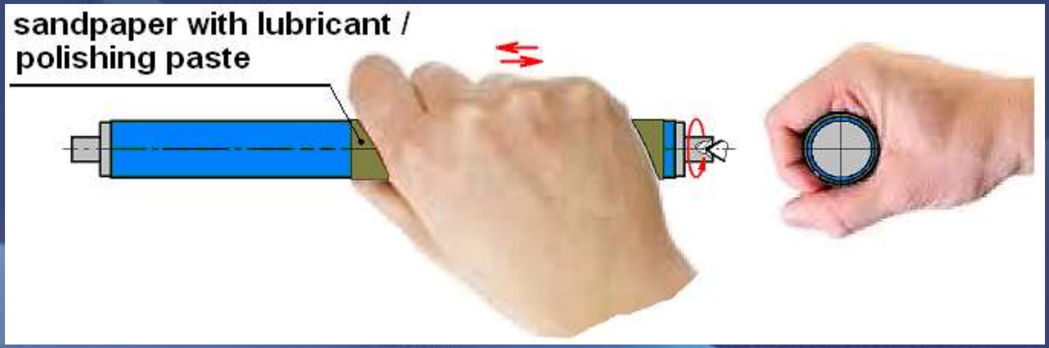
3.1.1. Minimal surface rougness and waviness (con't)

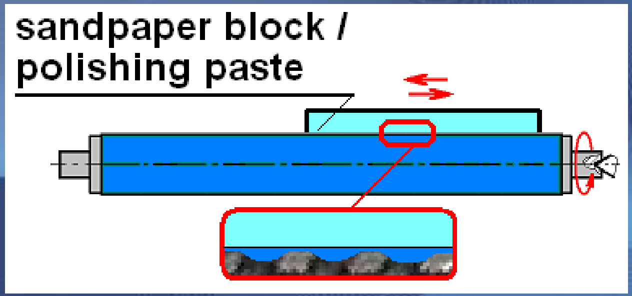
Lacquer coating



Grinding / polishing







SEE NOTE

3.2. Absence of groove/chamfer at the body-NC juncture

3.2.1. Use a rear ejection system.

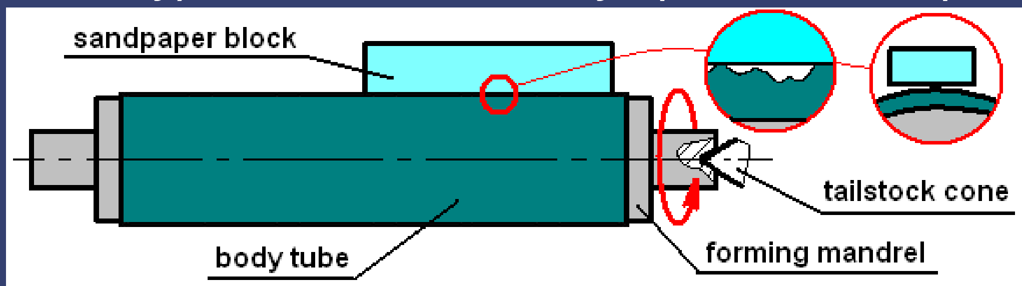
"… Flow calculations by Bob Parks show that boundary layer becomes turbulent at typical "elliptical nose-to-cylinder tube"

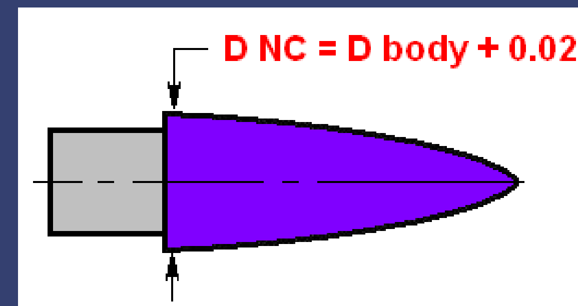
intersection…"

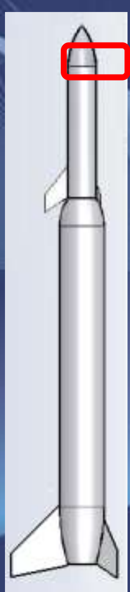
However, winners of "gold" and "silver" at WCh-2010 (CUDEN Joze and CUDEN Miha (both SLO)) and winner of "silver" at Ech-2011 (CUDEN Joze (SLO)) used a rear ejection system.

3.2.2. Smoothing the NC-Body juncture

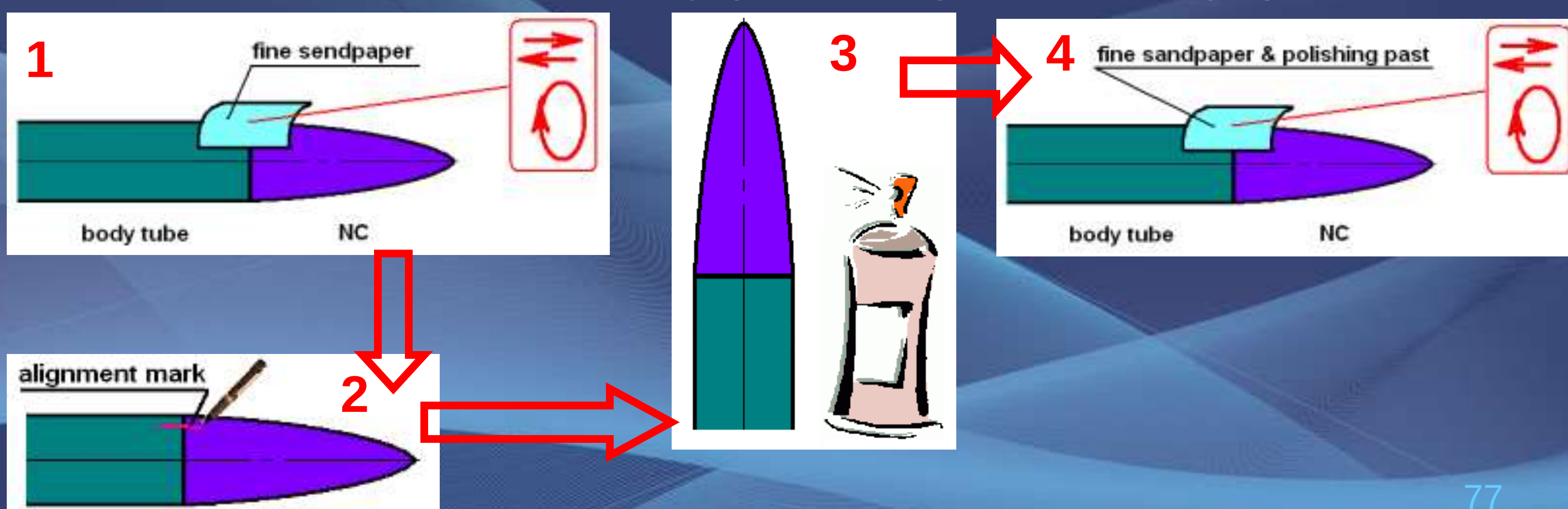
Approximately the same result (to remove groove at the juncture NC-Body) can be achieved by special technique.







After NC - NC shoulder assembly (slide # 41) the following operations:

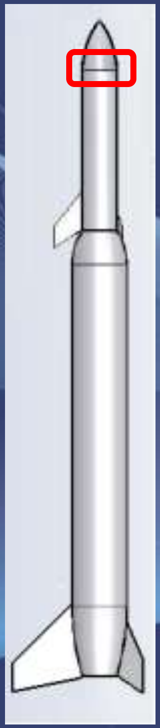


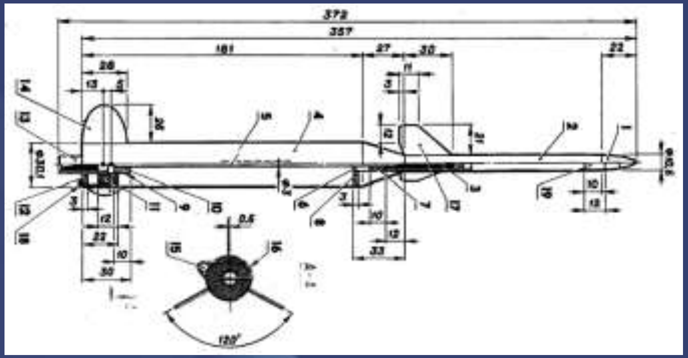
3.2.2. Smoothing the NC-Body juncture (Con't)

Results of Applications of the described Technique in the past

1. S1. EuCh-1993 – Alexander Mitiuriev. 1st place. 1178 m with 18% margin from 2nd place.

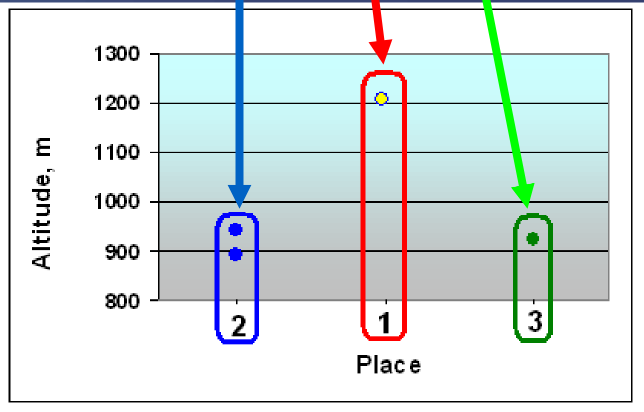
Mitiuriev's model :





2. Similar technique was applied by Voronov Oleg (RUS) . WCh-1996. S1. 1209 m with a wide margin (22 %) from 2nd place.

11th WCh-1996, Slovenia,
Podium S1A (L-R):
KREUTZ Robert (USA) – 2nd
VORONOV Oleg (RUS) – 1st
KORIAPIN Alexey (RUS) – 3rd

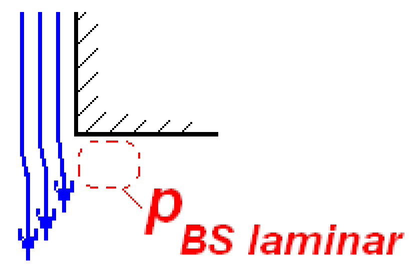


3.3. Base Drag Reduction

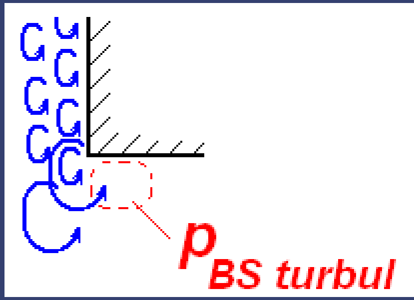
3.3.1. Turbulization of the air flow at the bottom of a body

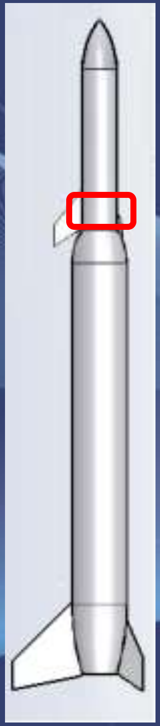
Flow at the body's Back Section

Laminar flow:



Turbulent flow:



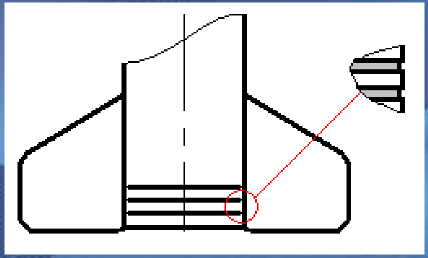


Pressure behind Back Section:

$$p_{\text{BS Lamin}} < p_{\text{BS Turbul}}$$

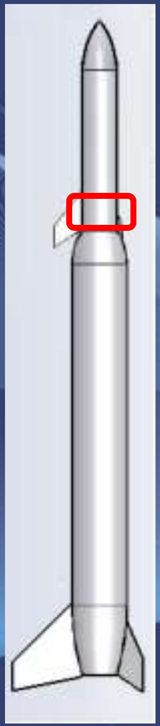
⇓

$$Cx_{\text{дон Ламин}} > Cx_{\text{дон Турбул}}$$

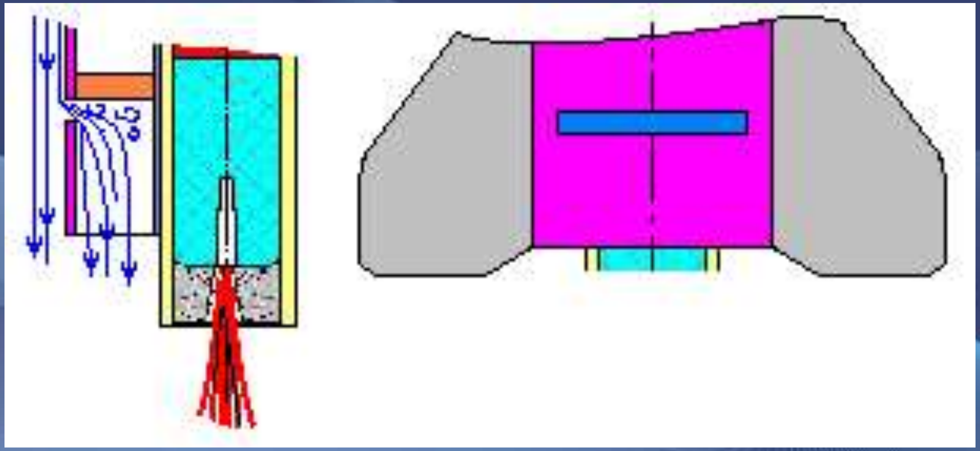


SEE NOTE

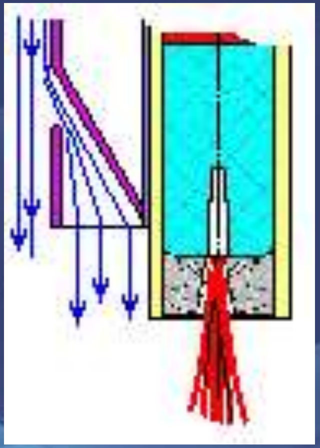
3.3.2. Air flow injection into the body's base region



Flow Slots:



Air Ducting Channel - Injector:

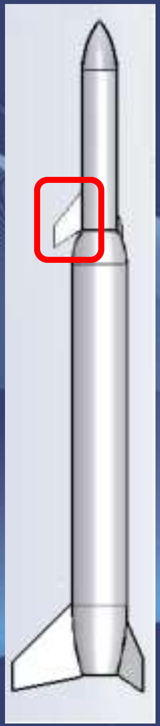


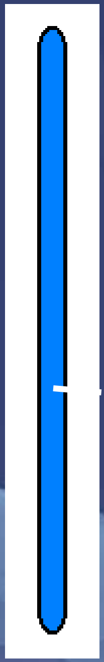
SEE NOTE

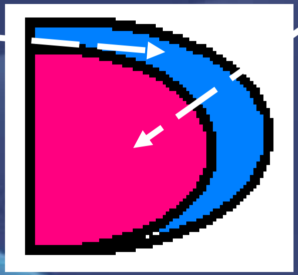
3.4. Fins

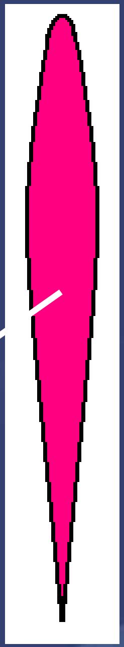
Flat profile:

Biconvex profile:









1. $Cd_{(flat)} > Cd_{(biconvex)}$

2. $(\partial C_N/\partial \alpha)_{(flat)} < (\partial C_N/\partial \alpha)_{(biconvex)}$

$\Downarrow$

$S_{(flat)} > S_{(biconvex)}$

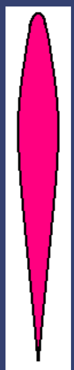
$\Downarrow$

$D_{frict\ (flat)} > D_{frict\ (biconvex)}$

SEE NOTE

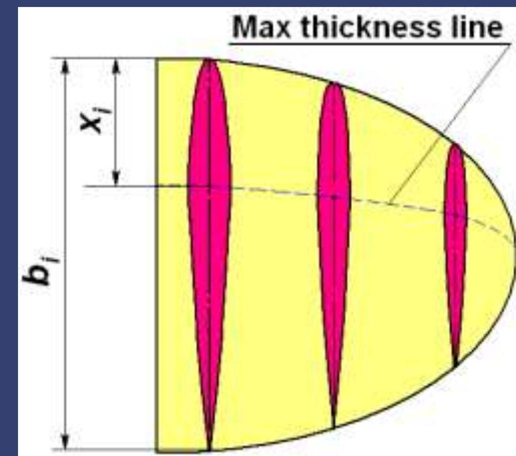
3.4. Fins (con't 1)

Biconvex profile

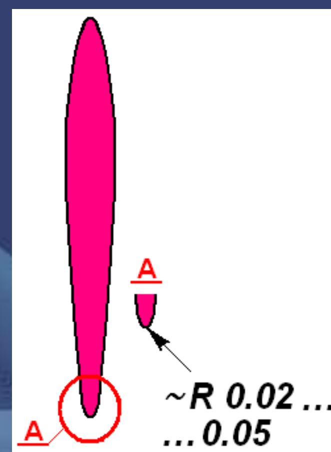


1. Maximum thickness point:

$$x_i \,/\, b_i \approx 1/4 \;\; \ldots \; 1/3 = \text{const}$$



2. Leading and
   Trailing edges

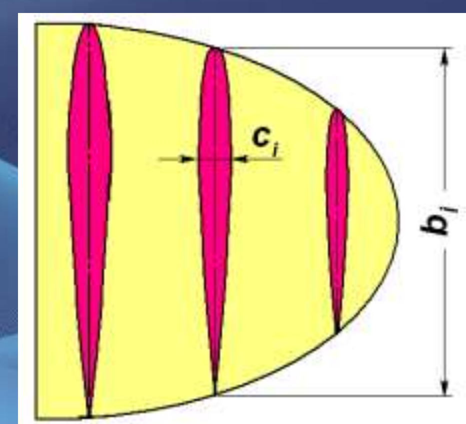


3. Fin's relative thickness:

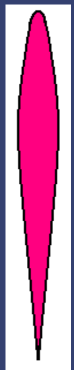
$$c_i \,/\, b_i = \text{const}$$

$$\Downarrow$$

$$(\partial C_N \,/\, \partial \alpha)_I = \text{const}$$



3.4. Fins (con't 2)



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

However,

$$(\partial C_N / \partial \alpha) = f\ (Re)$$

For elliptic or trapezoidal fins:

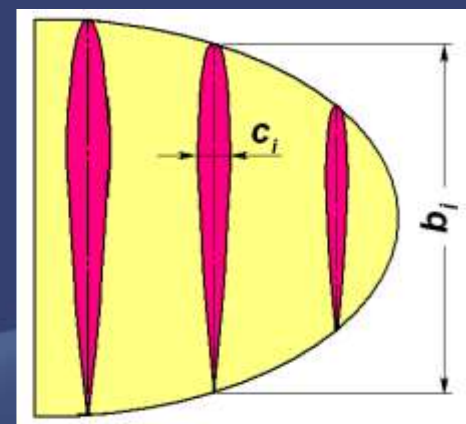
$$b_i = var$$

$$\Downarrow$$

$$Re_{\ i} = var$$

$$\Downarrow$$

$$(\partial C_N / \partial \alpha)_i = var$$



c_i/b_i = [ ] ⟹ $(\partial C_N / \partial \alpha)_i \approx const$

$f(b_i)$

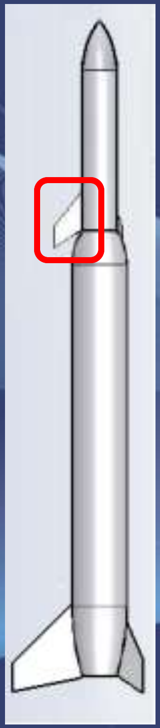
TBD

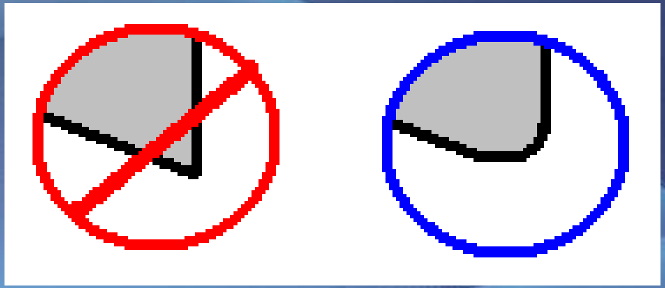
SEE NOTE

3.5. No sharp edges

1. Sharp edges are a source for airflow disturbances.

2. Sharp edges will be jammed (and worst of all - nonsymmetricaly) during handling and landing.



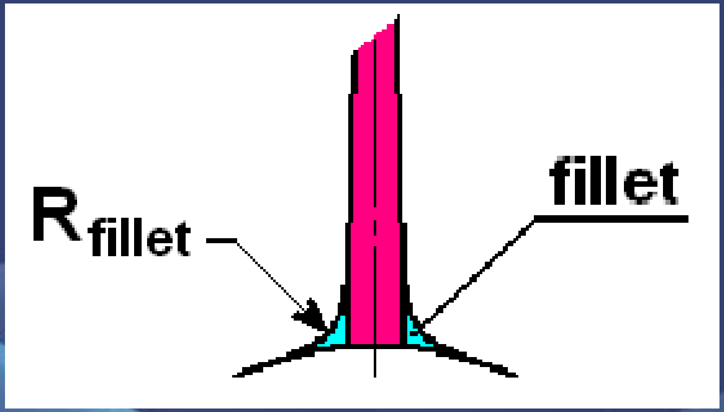


3.6. Body-fins fillet

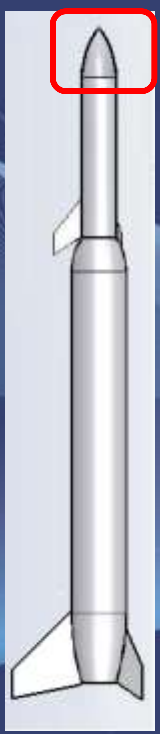
To reduce fins-body flow interference.

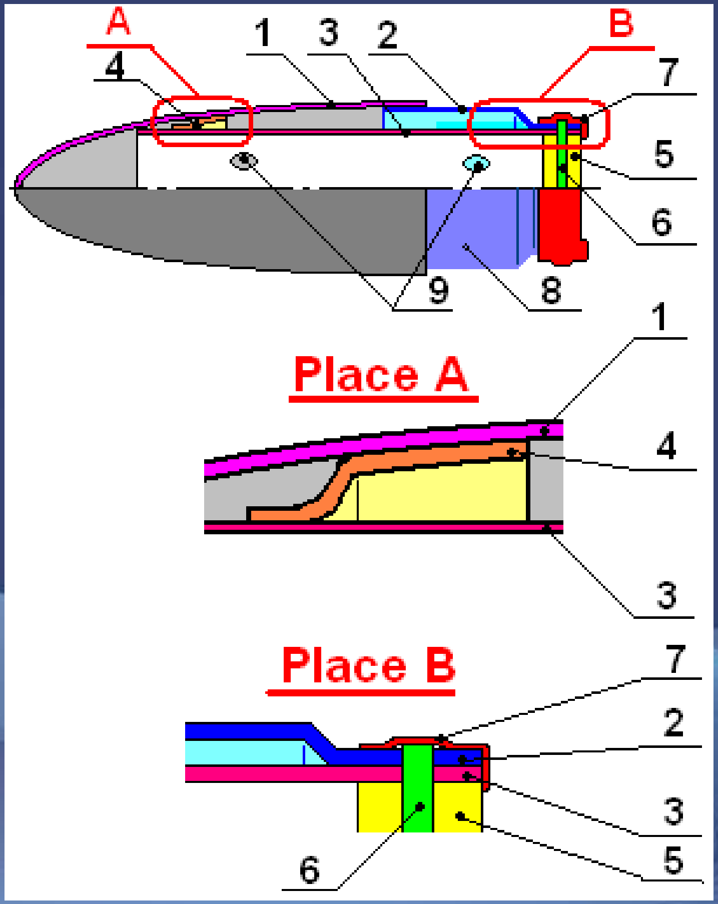
Comments:
Fillet radius should be equal on both sides and for all fins.
That assumes presumably molding technique.

R $_{fillet}$ - ?



3.7. Example of Altimeter setting inside of NC





1. NC body.
2. NC Shoulder.
3. Body of altimeter container.
4. Alignment shoulder.
5. End cap of altimeter container.
6. Lock pin.
7. Glue tape.
8. Vent holes in NC shoulder.
9. Vent holes (perforations) on the body of altimeter container.

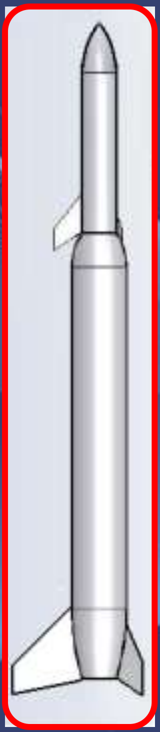
4. Materials

4.1. Paper vs. epoxy-fiberglass

Use Fiberglas-epoxy for body parts:

1st and 2nd stage Bodies; NC, engine mounts, …

Do not use paper.



A. Strength-to-weight ratio.

Paper has a lower strength-to-weight ratio.

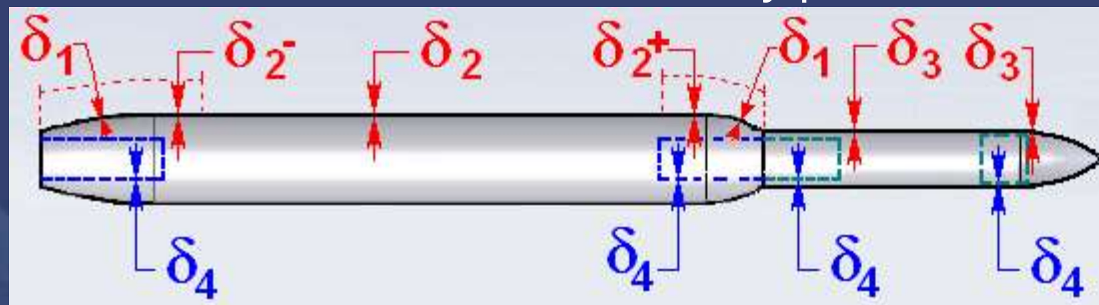
B. Resistance to moisture.

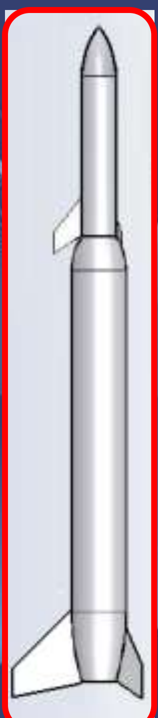
Paper has NO resistance to moisture.

SEE NOTE

4.2. Fiberglas-epoxy parts wall thickness

Recommended wall thickness of model body parts:





	Part	δ	Number of Fiberglass layers (Δ = 0.025 mm)	Recommended Wall Thickness, mm	Measurement instrument
External parts	Aft Cone	δ1	2	0.08 - 0.10	visual
	1st Stage body cylinder	δ2	2	0.08 - 0.10	micrometer
		δ2	2	0.06 - 0.07	micrometer
		δ2	2	0.08 - 0.10	micrometer
	Transitional Cone	δ1	2	0.08 - 0.10	visual
	2nd Stage body cylinder	δ3	4	~ 0.15	micrometer
	Nose Cone	δ3	4	~ 0.15	micrometer
Internal parts	1st Stage engine mount	δ4	3	~ 0.12	micrometer
	Interstage fitting cylinder	δ4	3	~ 0.12	micrometer
	2nd Stage engine mount	δ4	3	~ 0.12	micrometer
	NC shoulder	δ4	3	~ 0.12	micrometer

SEE NOTE

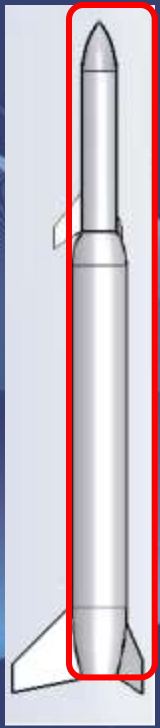
4.3. External surfaces lacquer coating

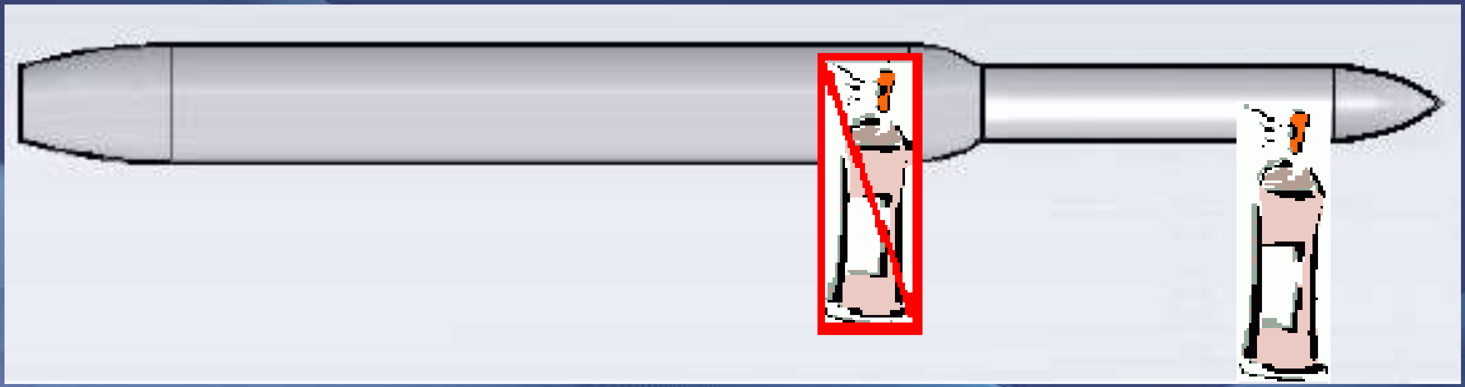
A. 1st Stage

No lacquer coat.

B. 2nd Stage

Lacquer coated and polished.





SEE NOTE

5. Engines

5.1. 1st Stage Engine

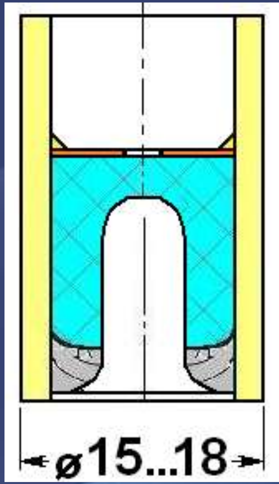
5.1.1. Engines Thrust diagram / burn time

Burn time ↓ ⇒ Mass of fuel burned inside piston ↑ ⇒
⇒ Exhaust gas Pressure ↑ ⇒
⇒ (Piston + Model) velocity ↑ ⇒ Burn-out velocity ↑

But then:

Burn time ↓ ⇒ Engine's OD ↑ ⇒
⇒ Engine's wall thickness and Nozzle weight ↑ ⇒
⇒ Engine's weight ↑ ⇒ Burnout velocity ↓

Possible outcome of optimization:



How fast an engine should be - ?

TBD

SEE NOTE

5.1. 1st Stage Engine (con't)

5.1.2. BP engines vs. compound engines.

BP Fuel mass > Compound Fuel mass ⇒
⇒ Mass of BP burned inside piston > Mass of Compound burned inside piston
⇒ Exhaust BP gas Pressure > Exhaust Compound gas Pressure ⇒
⇒ (Piston + Model) BP velocity > (Piston + Model) Compound velocity ⇒
⇒ Burnout BP velocity > Burnout Compound velocity

But then:

Exhaust BP gas Temperature < Exhaust Compound gas Temperature ⇒
⇒ Exhaust BP gas Pressure < Exhaust Compound gas Pressure ⇒
⇒ (Piston + Model) BP velocity < (Piston + Model) Compound velocity ⇒

⇒ Burnout BP velocity < Burnout Compound velocity

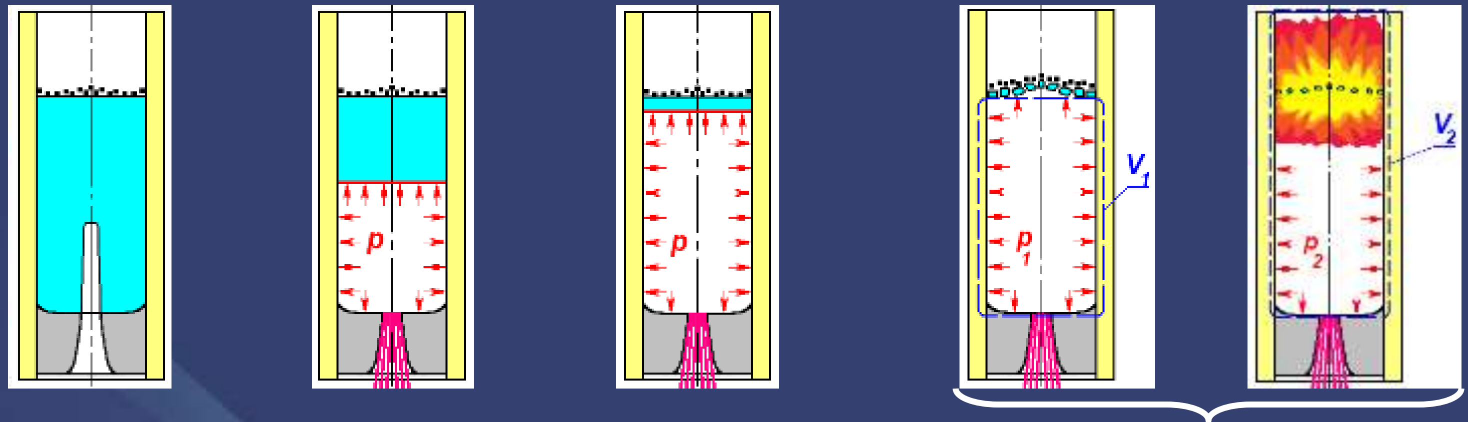
BP or compound engine - ?

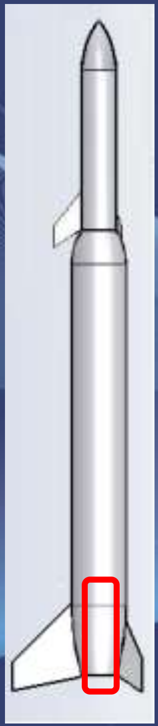
TBD

SEE NOTE

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

Engine with open Solid Grain. Propellant burning





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

At a breakage of solid grain's top part:

GC volume: $V_{GC} \uparrow (V_{GC\,2} > V_{GC\,1})$

$\Downarrow$

Pressure inside of GC: $p_{GC} \downarrow (p_{GC\,2} < p_{GC\,1})$

$\Downarrow$

Exhaust Gas Velocity / Specific Impuls: $v_e \downarrow$ / $I_{sp} \downarrow$

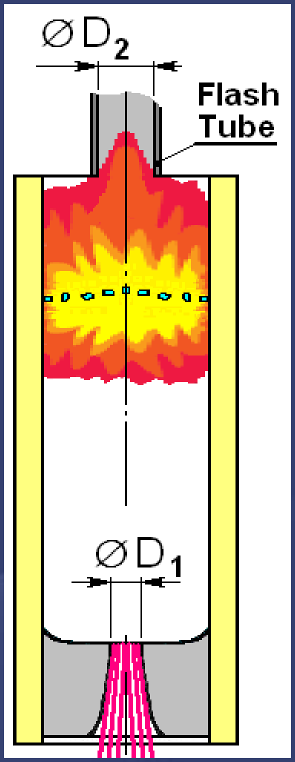
$\Downarrow$

Total Impuls: $I_\Sigma \downarrow$

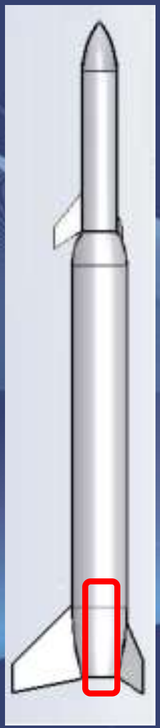
SEE NOTE

5.1.3.2. Decrease of a total impuls as a result of 2nd outlet forming

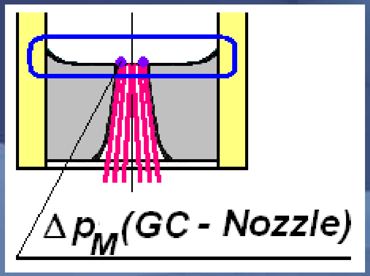
$\varnothing D_1$ (Nozzle) ≈ 1.6 mm < $\varnothing D_2$ (Flash Tube) ≈ 3 mm

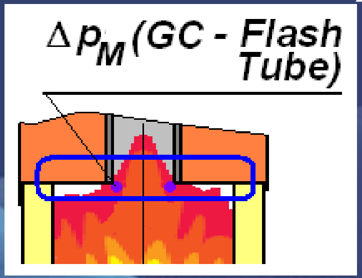


Hydraulic resistance / pressure loss, Δp_m :



Δp_m (GC – Nozzle) ≈ 1.1 Δp_m (GC – Flash Tube)



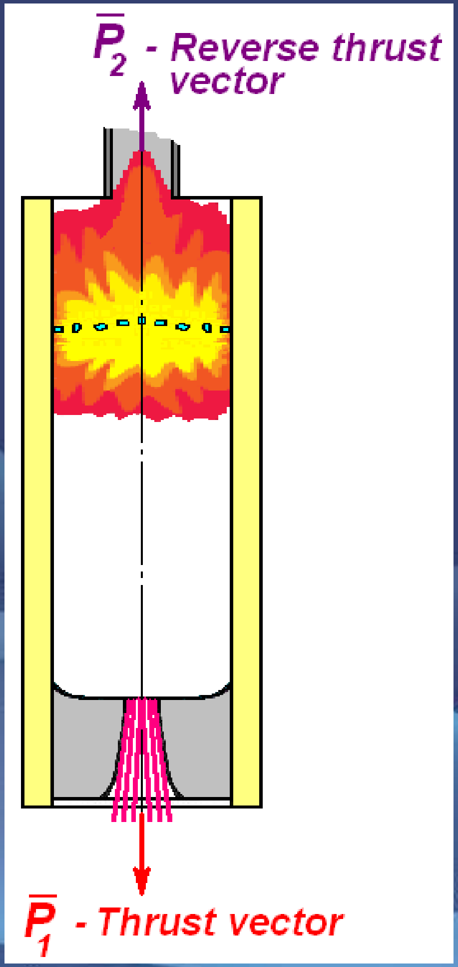


Mass of exhaust product through a nozzle, m_p ↓

Total Impuls: I_Σ ↓

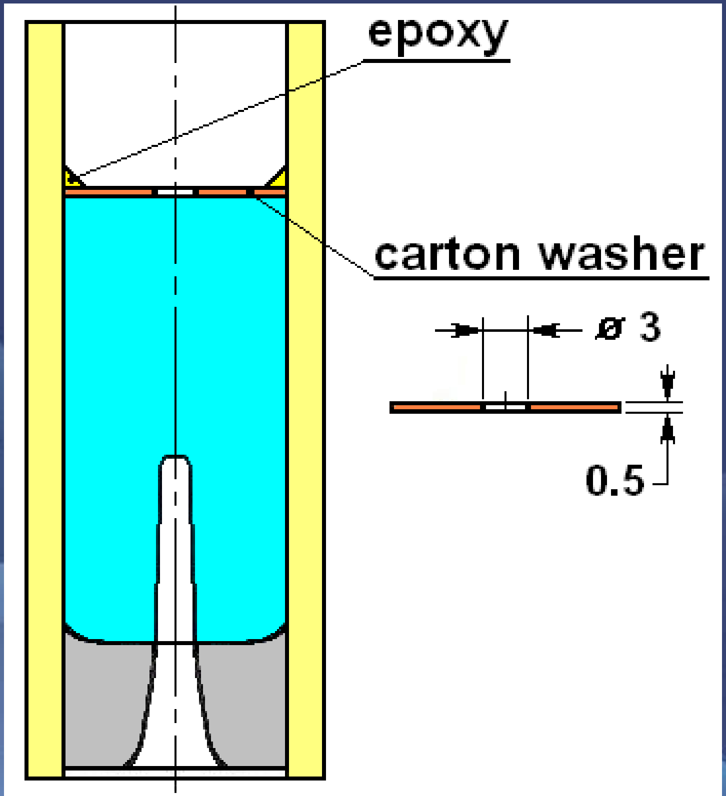
SEE NOTE

5.1.3.3. Reverse thrust



SEE NOTE

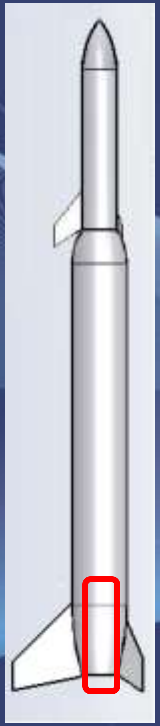
5.1.3.4. Forming a Top End for Grain Chamber

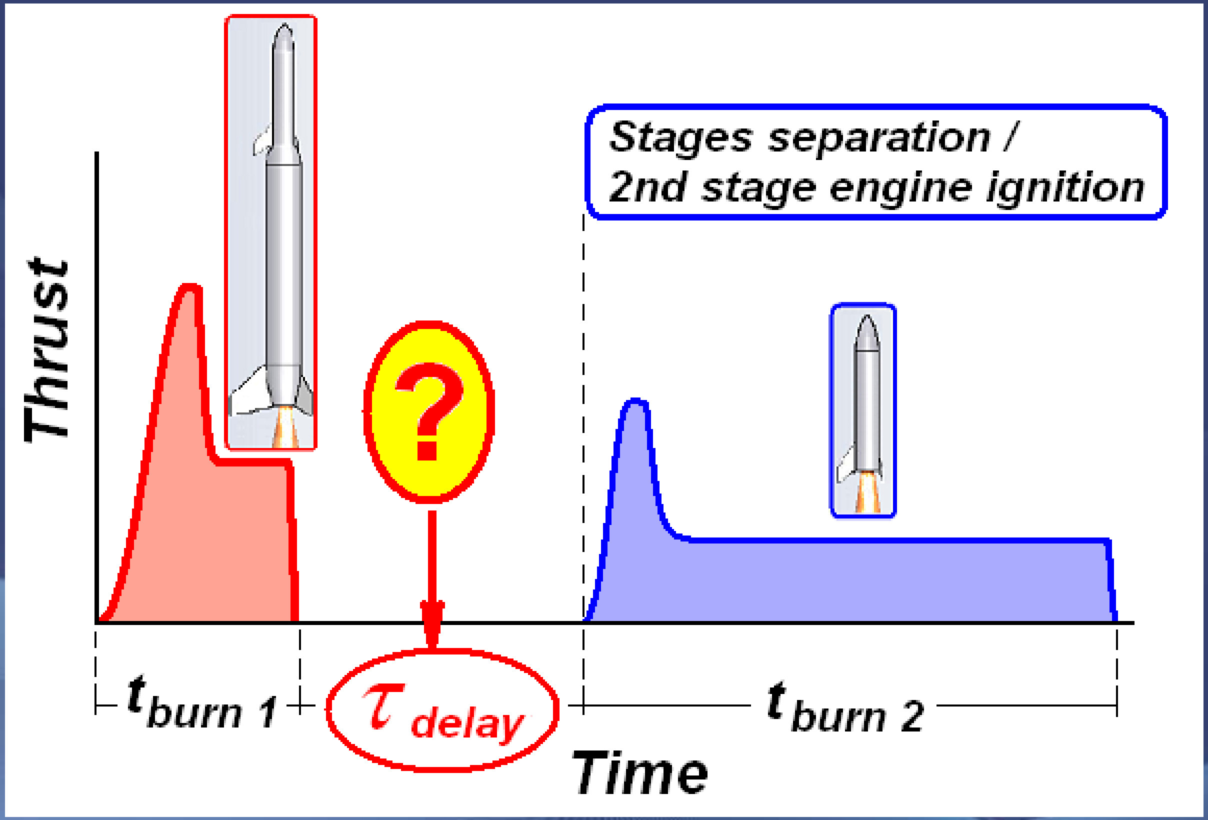


Appl for S5

SEE NOTE

5.1.4. Delay time for the 1st stage engine





SEE NOTE

5.1.4.1. External ballistic

1. $\tau_{delay} > 0 \Rightarrow \Delta h_{coast\ 1st\ stage} > 0 \Rightarrow h_{\Sigma\ 1st\ stage} \uparrow$

2. $\tau_{delay} > 0 \Rightarrow V_{0\ 2nd\ stage} \downarrow \Rightarrow h_{\Sigma\ 2nd\ stage} \downarrow$

aerodynamic loss of velocity, $\Delta V_{a/d} \uparrow \Rightarrow h_{\Sigma\ model} \downarrow$

$\Downarrow$

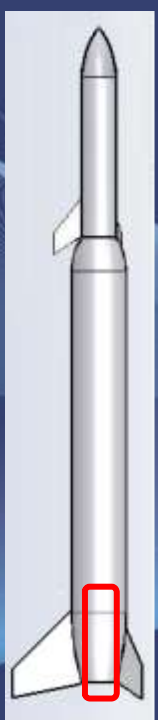
The earlier the stages separation and the firing of the 2nd stage engine will take place, the greater altitude a model will reach.

$\Downarrow$

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

SEE NOTE

5.1.4.1.1. Decrease of air density (ρ) during flight:



S1 model

τ_{delay} = 1 sek
$\Delta h \approx 50$ m
$\Delta \rho \approx 0.5\%$
$\rho_1 \approx \rho_2$

«Pershing-2»

$\rho_2 << \rho_1$

Δ ρ (S1) $_{max}$ **<< Δ ρ («Pershing-2»)**

There is no effect of air density decrease (attributable to flights of real rockets) during flights of S1 models.

SEE NOTE

5.1.4.1.2. Ballistic Coefficient (BC)

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

$$BC = (2 \cdot m) / (Cx \cdot S)$$

Ballistic Coefficients Values:

S1 model	«Pershing -2»

BC (S1 model) ≈ 1/300 · BC («Pershing-2»)

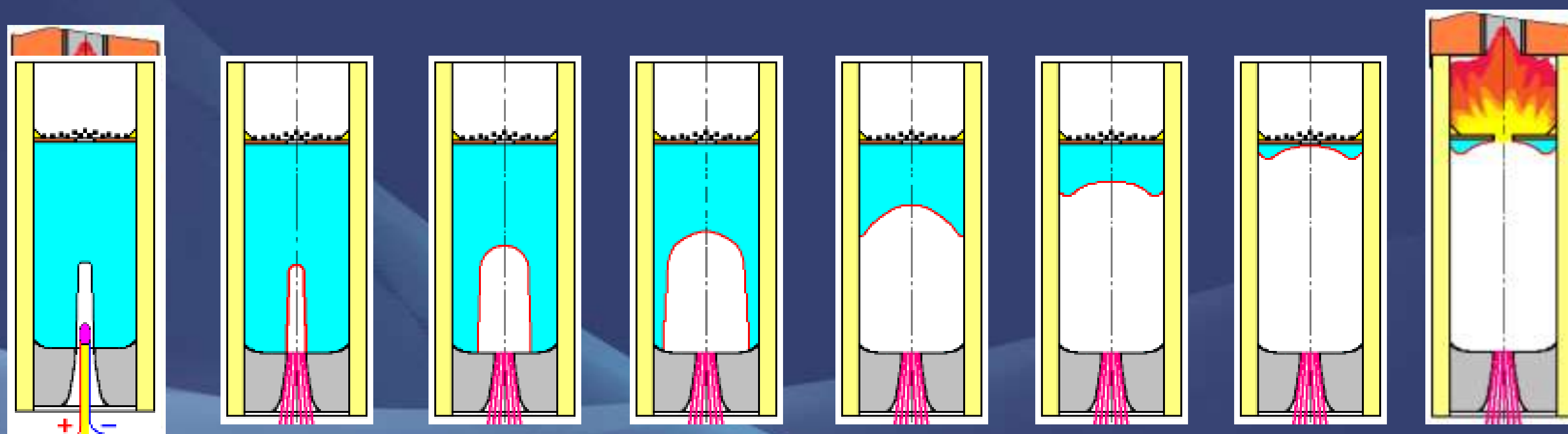
Models S1 are substantially less dence than real rockets, and they decelerate very fast during a coastal flight.

There is no similarity on Ballistic Coefficient parameter between S1 models and real rockets.

SEE NOTE

5.1.4.2. Internal ballistic

Solid Grain burning inside of a Grain Chamber:

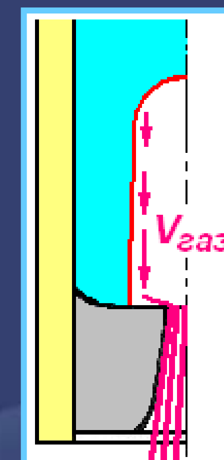


SEE NOTE

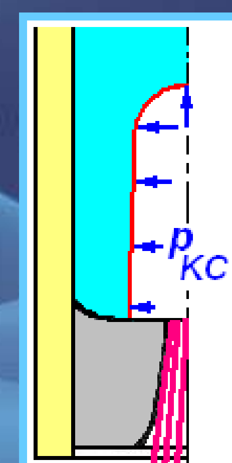
5.1.4.2.1. Burning rate and burning front shape of a Solid Grain during the phase of the internal-channel burning

Impact factors on burning rate:

1. Local combustion gas velocity on the burning surface, V_{gas}

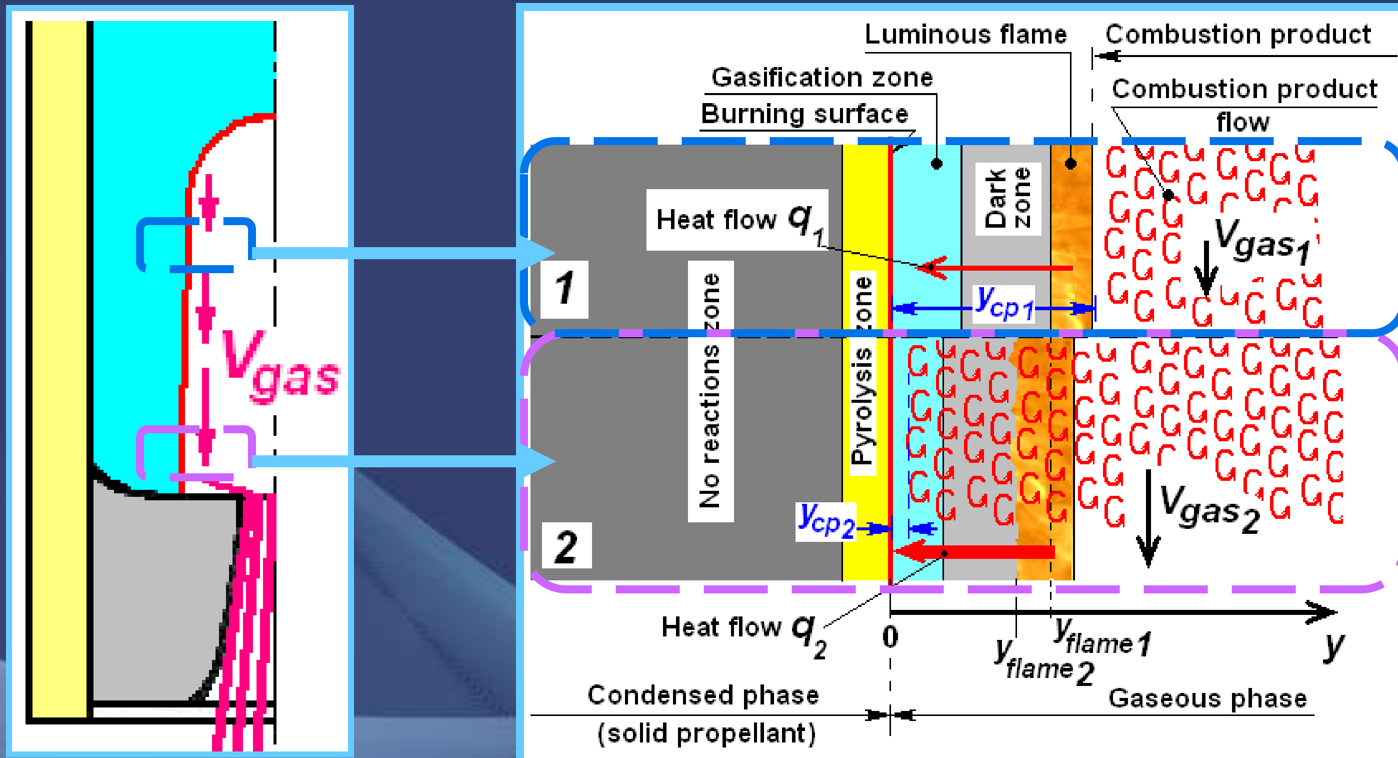


2. Internal ballistic parameters of the combustion gas (first and foremost – the pressure) on the burning surface.



SEE NOTE

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



Schematic of the propellant burning on the channel surface. Combustion gas flow velocity

Where :

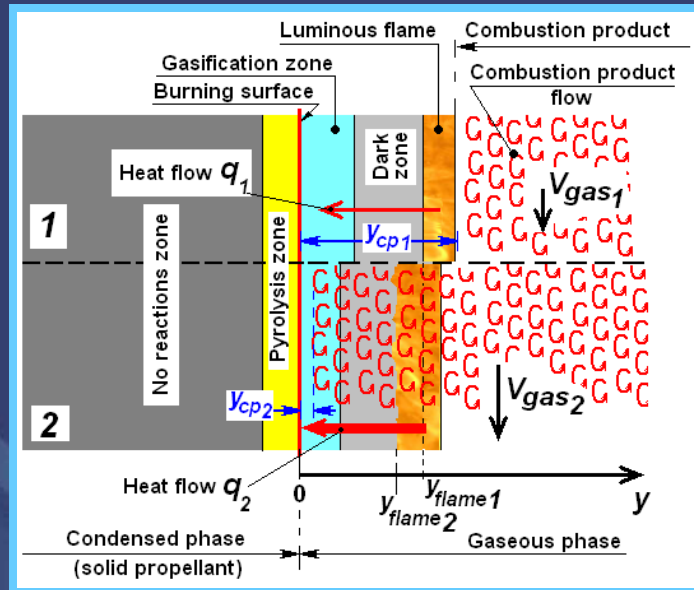
V_{gas} - Local combustion gas velocity on the burning surface;

y_{cp} – Distance between turbulent core of Combustion gas flow and the burning surface (Propellant's solid surface);

y_{flame} – Distance between Luminous (flaming) Burning zone and the burning surface (propellant's solid surface)

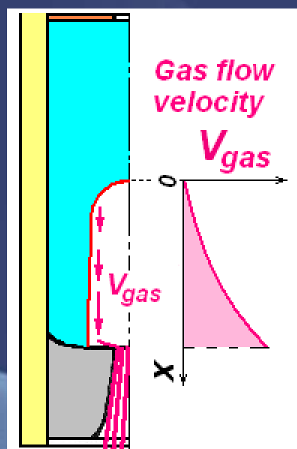
SEE NOTE

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



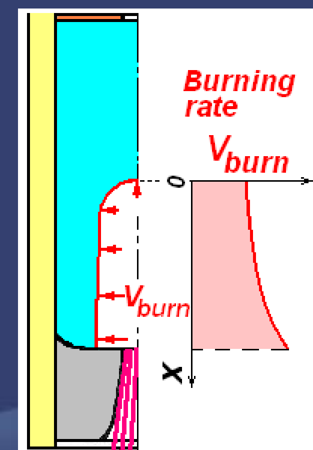
Gas flow velocity profile

V_{gas} :

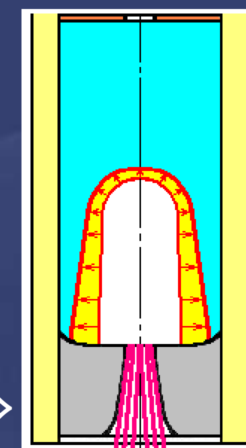


Burning rate profile

V_{burn} :



Convexity decrease of burning front shape :



$V_{gas}(x) \uparrow$ ⇒

Distance between turbulent core of Combustion gas flow and the burning surface :

$y_{CP}(x) \downarrow \quad (y_{CP2} < y_{CP1})$

⇙

Turbulization of burning zone ⇒

Heat flow

$q(x) \uparrow \quad (q_2 > q_1)$

⇒

Enhancement of chemical reactions

⇑

$V_{burn}(x) \uparrow$ ⇒

SEE NOTE

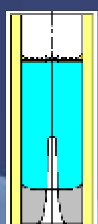
5.1.4.2.2. Local combustion gas velocity on the burning surface. Erosive burning (con't 2)

Condition of Erosive burning existence :

1. V_{th} – Threshold flow velocity: $V_{gas} > V_{th}$
2. $(\rho_{th} \cdot V_{th})$ - Threshold mass flux velocity :

$$(\rho_{gas} \cdot V_{gas}) > (\rho_{th} \cdot V_{th})$$

, where ρ – dencity of Combustion product in a flow



Model Rocket Engines (MRE) | **Solid Fuel Rocket Engines (SFRE) of real rockets**

1. $V_{gas\ MRE} < V_{gas\ SFRE}$

2. $(\rho_{gas\ MRE} \cdot V_{gas\ MRE}) < (\rho_{gas\ SFRE} \cdot V_{gas\ SFRE})$

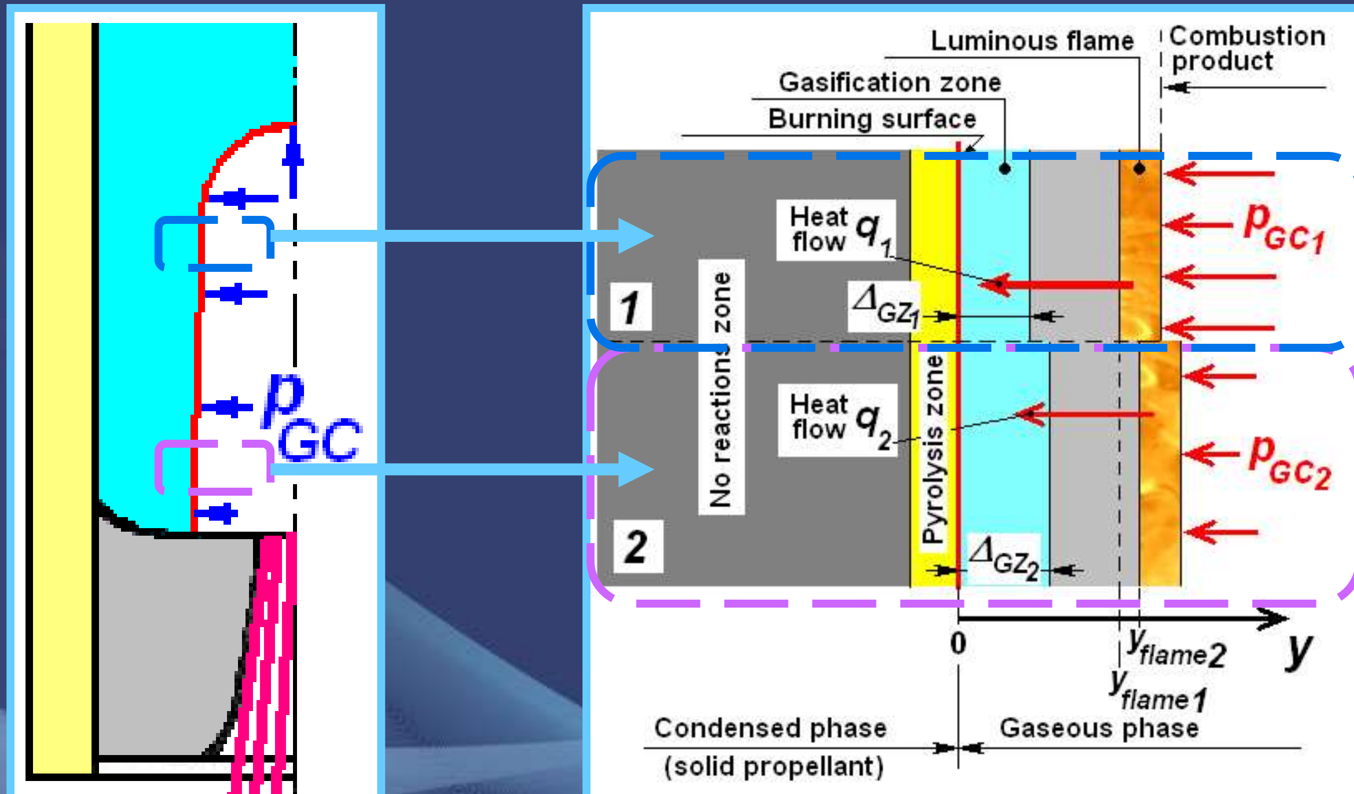
$(V_{gas\ MRE})_{max} > V_{th\ MRE}$ - ?

$(\rho_{gas\ MRE} \cdot V_{gas\ MRE})_{max} > (\rho \cdot V)_{th}$ - ?

Erosive burning in MRE - ?

SEE NOTE

5.1.4.2.3. Local pressure of combustion gas on the burning surface



Schematic of the propellant burning on the channel surface.
Local pressure of combustion gas flow

Where:

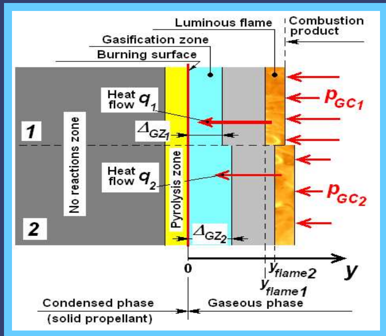
P_{GC} - Local pressure of combustion gas on the burning surface;

Δ_{GZ} - Thickness of Gasification zone;

y_{flame} - Distance between Luminous (flaming) Burning zone and the burning surface (propellant's solid surface).

SEE NOTE

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

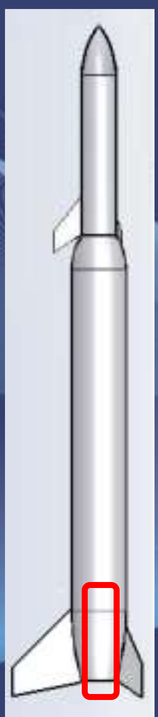


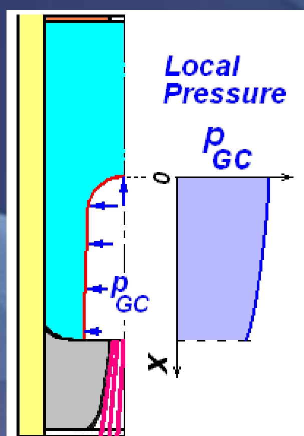
$$v_{burn}(p) = k \cdot p^n,$$
where $n > 0$

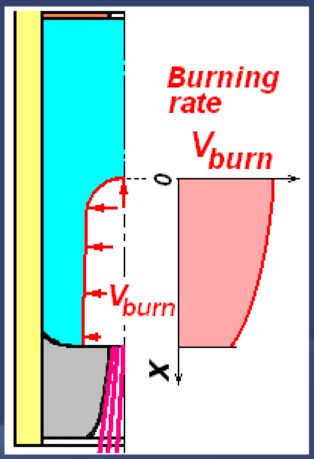
Burning rate profile V_{burn} :

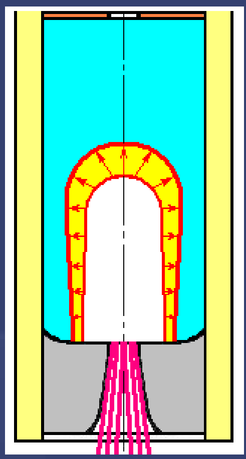
Convexity increase of burning front shape :

Local pressure profile p_{GC} :









Distance between Luminous flame and the burning surface $y_{CP}(x)\uparrow$

⇒

Heat flow $q \downarrow (q_2 < q_1)$

⇓

⇑

Thickness of Gasification zone $\Delta_{GZ}(x)\uparrow$

⇗

$p_{GC}(x)\downarrow$

⇘

Concentration of gaseous reactants $(x)\downarrow$

⇒

Rate of chemical reactions with gas generation in the Solid phase $(x)\downarrow$

⇒

$V_{burn}(x)\downarrow$

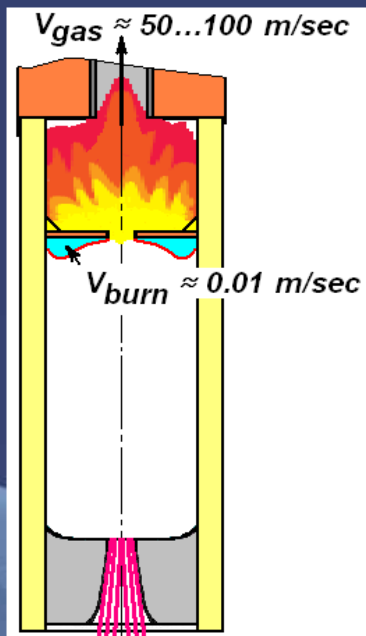
⇑

⇑

Rate of exothermic reactions in the Gaseous phase $(x)\downarrow$

SEE NOTE

5.1.4.2.4. Internal ballistic and stages separation



$V_{burn} \approx 0.01$ m/sec

$V_{gas} \approx 50…100$ m/sec

⇒

⇒

Flight of PEREVEROV's Mikhail (Russia) scale model Ariane-3 V10 (S7), WSMC-2012.

Stages separation

Mass of exhaust product through a nozzle: $m_{ex} \downarrow$

⇓

Total Impuls: $I_{\Sigma} \downarrow$

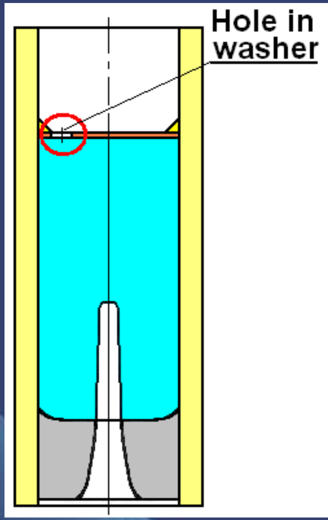
SEE NOTE

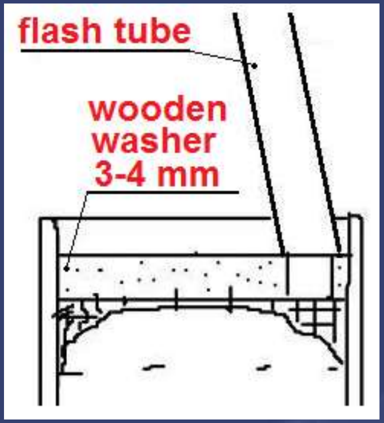
5.1.4.3. Prevention of a Total Impuls loss for 1st stage engine

Suggested solutions: Appl for S5

Similar solution usage in the past:

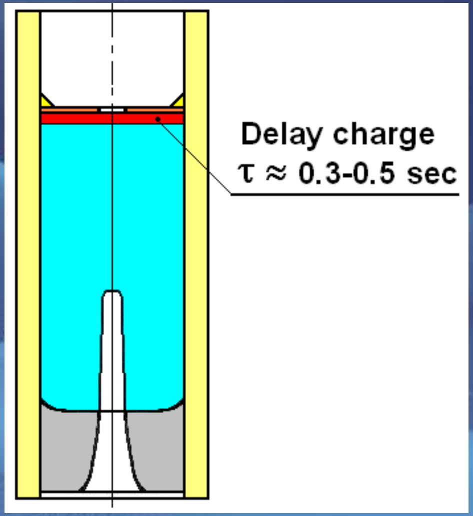
1. Off center hole in a washer





2. Small delay time for 1st stage engine

$$\tau_{delay} = 0.3\text{-}0.5 \text{ sec}$$



SEE NOTE

5.2. 2nd Stage Engine

Engines Thrust diagram / burn time.

Among the top contributors to the highest results in S1 is efficiency of 2nd stage engine. Currently some of the best engines in the category are:

- Taborsky's (Czech) "Delta A-2-7":

TABORSKY
Jiri

(Specific Impulse I_{sp} = 1200 (N·sec)/kg,

t_{burn} = 1.5 sec)

SEE NOTE

5.2. 2nd Stage Engine (con’t 1)

For ref: 6 out of 7 world champions (8 out of 9 titles) during the last 20 years (since 1992) got their title using Jiri Taborsky’s “Delta” engines.

1992 - VINCENT Jeff (USA)

1996 - VORONOV Oleg (RUS)

1998 - MENSHIKOV Vladimir (RUS)

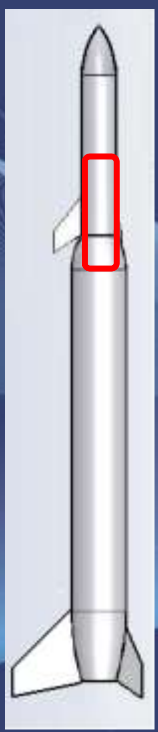
2000 - CUDEN Joze (SLO)

2002 - ŠIJANEC Anton (SLO)

2004 - MAZZARACCHIO Antonio (ITA)

2006 - MENSHIKOV Vladimir (RUS)

2010 - CUDEN Joze (SLO)



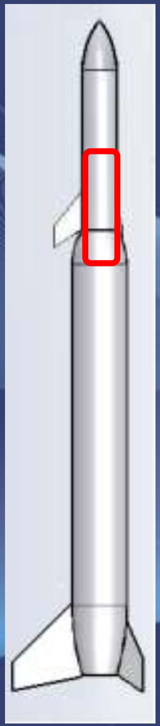
5.2. 2nd Stage Engine (con't 2)

- Hapon's (Ukraine) "Zenit A-2":

Yuri HAPON

Specific Impulse $I_{sp} \approx 1200$ (N·sec)/kg,
t_{burn} = 1.5 sec

Piotr SORNOWSKI



- Piotr SORNOWSKI'S (Poland) "PSn A1-4-8":

Specific Impulse $I_{sp} \approx 1200$ (N·sec)/kg,
t_{burn} = 4 sec

For reference:

World champion (WSMC-2012) Maksim TIMOFEJEV (LTU) used Piotr SORNOWSKI'S engines for 1st and 2nd stages.

2012 - Maksim TIMOFEJEV (LTU)

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

However, it is possible that a longer burning engine (longer than t_{burn} = 1.5 sec) will be more efficient.

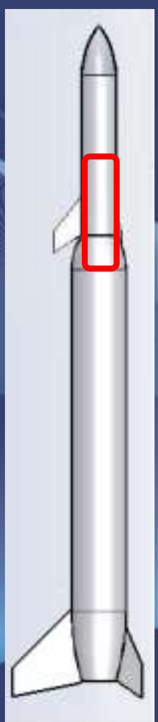
Yes,

$t_{burn} \uparrow$ ⇒ Velocity's gravity losses $\Delta V_g = (t_{burn} \cdot g) \uparrow$

Thus, every second of engine burning time reduces final velocity **V_{burn}** by the value of velocity's gravity losses of **10 m/sec**:

$$\Delta V_g\ (t_{burn} = 1\ sec) = t_{burn} \cdot g = 1\ sec \cdot 9.81\ m/sec^2 \approx 10\ m/sec$$

$$V_{burn} \downarrow \Rightarrow H_{flight} \downarrow$$



But at the same time:

$$t_{burn} \uparrow \Rightarrow V_{average\ burn} \downarrow \Rightarrow \text{Velocity's aerodynamic drug losses } \Delta V_d \downarrow \Rightarrow$$

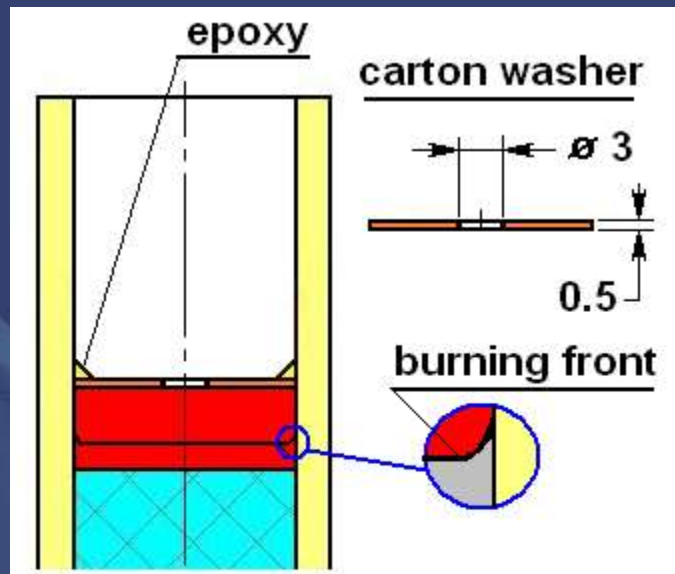
$$\Rightarrow H_{burn} \uparrow \Rightarrow H_{flight} \uparrow$$

Optimal t_{burn} - ? **TBD**

5.3. Delay time increase (2nd Stage Engine)

5.3.1. Delay increase by 0.3 … 0.5 sec.

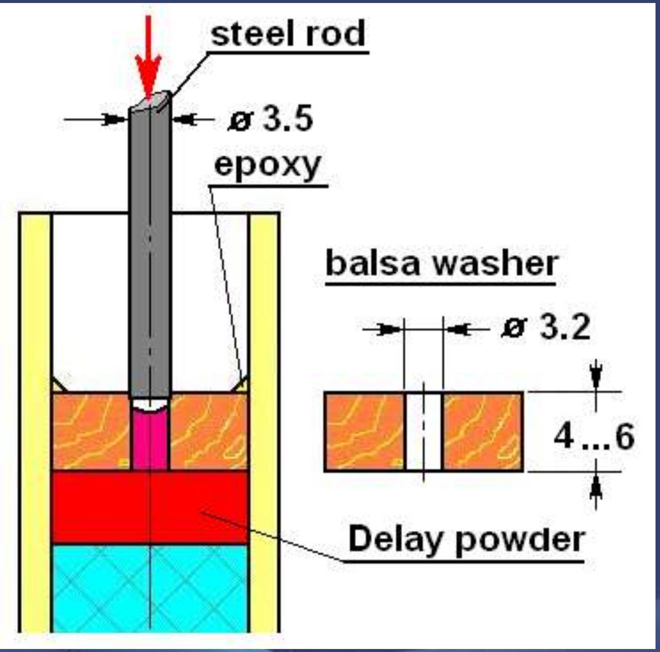
Appl for S5



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

SEE NOTE

5.3.2. Delay increase by more than 0.5 sec.



Appl for S5

- Insert a balsa washer inside the engine on the top of the delay and glue it with epoxy.
- Put an additional delay powder inside a washer hole. Press this powder in with a steel rod by hand. Do not strike.

SEE NOTE

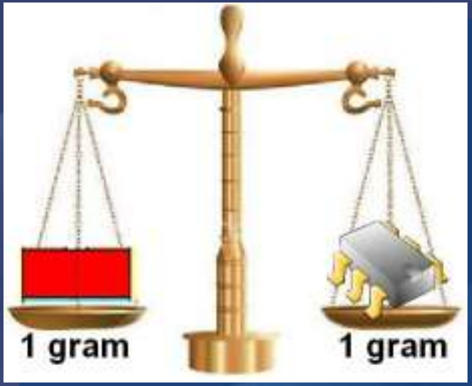
5.4. Delay replacement

Appl for S5

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

Background:

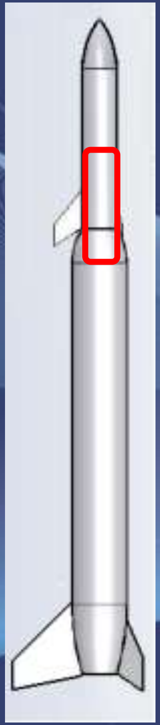
1. **The weight of the current traditional delays for the engines used for 2nd stages is about 1 gram (for engines with OD 10 - 11 mm and $t_{delay} \approx 4 - 6$ sec).**
2. It is possible now to make an electronic delay device with a weight of about "the same" 1 gram.

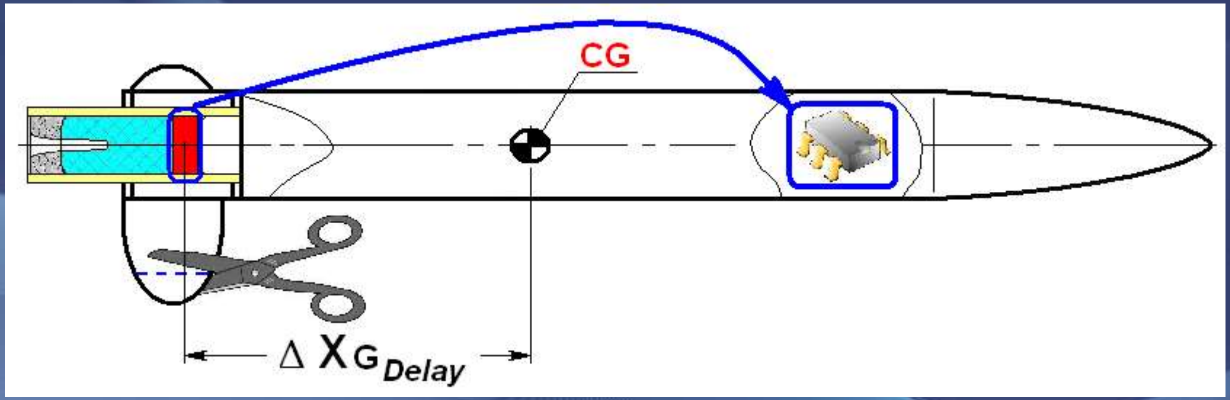


5.4.1. Location of engine's delay

1. The location of engine's delay is always below the model's (2nd stage's) Center of Gravity.

2. A relocation of the delay up to the Nose Cone will allow to reduce a fin's total area.

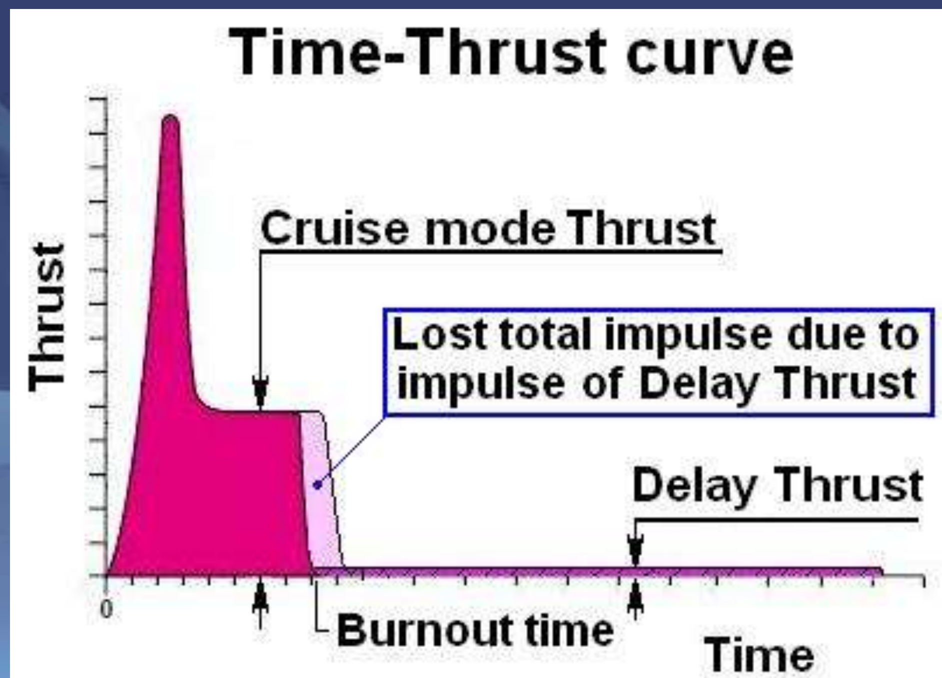




5.4.2. Delay's "parasitic" Total Impulse

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.



SEE NOTE

5.4.3. Delay and model's ballistic coefficient

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

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

SEE NOTE

6. Piston

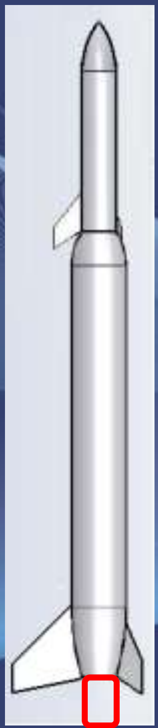
6.1. Some Physics and Math behind a Piston

Consider the fact that the time interval ($t_{on\ piston}$) between engine's ignition and the separation from a piston for relatively light models ($M_{(model\ +\ piston\ tube)}$ = 30 - 50 gram):

$$t_{on\ piston} \approx 0.1 - 0.15 \text{ sec}$$

Let's estimate **power** and **kinetic energy** division between a **model** and **exhaust gases** during this 0.1 sec for a model launched without a piston.

To be definite we will consider the following specific case:



Initial model's weight **m_0 = 30 g**

Let's consider "MRD-A-3" (Hapon & Co, Ukraine) (for example) as the engine for a 1st stage:
Propellant – BP: V_e = 919 m/sec,
I_Σ = 2.48 N·sec,
t_{burn}= 1.3 sec,
$m_{propellant}$ = 2.7 g

Simplifying, thrust F(t) = const
F = 1.91 N
$m_{t\ sec}$ = 2.1 g/sec
$m_{burn\ propellant}$ (t=0.1 sec) ≈ 0.21 g

SEE NOTE

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:

$$V(t=0.1\ \text{sec}) = -V_e \cdot \ln(m_1 / m_0) - g \cdot t = 5.4\ \text{m/sec}$$

Model's Power and Kinetic energy :

$$N_{model}\ (t=0.1\ \text{sec}) = v \cdot (F - m \cdot g - D) - 0.5 \cdot m_{t\ sec} \cdot V^2 = 8.7\ \text{W}$$

$$K_{model}\ (t=0.1\ \text{sec}) = 0.5 \cdot m_{model} (v_{model})^2 = 0.43\ \text{J}$$

Exhaust gases Power and Kinetic energy :

$$N_{exh\ g} = 0.5 \cdot m_{t\ sec} \cdot (V - V_e)^2 = 866\ \text{W}$$

$$K_{exh\ g}\ (t=0.1\ \text{sec}) = 0.5 \cdot m_{exh\ g} (v_{exh\ g})^2 = 88.1\ \text{J}$$

$$N_{exh\ g} = 100 \cdot N_{model}$$

$$K_{exh\ g} = 200 \cdot K_{model}$$

100 (!) times

200 (!) times

SEE NOTE

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 - 2.9 10^6 J/kg.**

Q (0.21 g of BP) = 580 Joules.

Then:

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

or $Q_{BP} = 1350 \cdot K_{model}$

1350 (!!!) times

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.

Ref: 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.

SEE NOTE

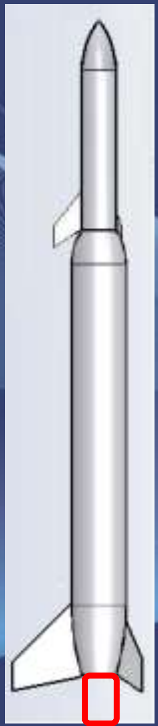
6.1. Some Physics and Math behind a Piston (con't 3)

Let's view something similar to a rocket modeling piston, a rifle's cartridges / bullets.

Efficiency rate of the powder (smokeless in modern ammunition) in cartridges (from the most popular **22LR** to the more sophisticated (for example the **Sierra 142 MK**)) is about **25-33%.**

By a very rough estimations of the model's velocity at the separation point from a piston (for European/Russian piston type, see below) is in a range of 10 - 20 m/sec.

Thus, the model's Kinetic Energy is:



$$K = 0.5 \cdot m_{model} (v_{model})^2 = 1.5 - 6 \text{ J}$$

$$\eta = K_{model} (t=0.1 \text{ sec}) / Q (0.21 \text{ g of BP}) = (1.5 - 6) \text{ J} / 580 \text{ J} = 0.0025 - 0.010$$

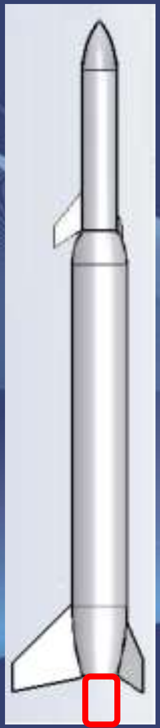
Yes, **0.25 - 1.0 %** of the propellant internal energy is much less than the cartridge-rifle-bullet's efficiency of **25-33%.** However, these values are not microscopic (**0.075 %**) of no-piston-case either.

Of course, the most powerful industry in the world, the military industry was able to «squeeze» as much as possible from a few grains of powder during centuries. A gargantuan **gap between 0.075%** (and even **1%** for currently the most sophisticated European style pistons) and **25-33%** is an indicator that something can be done for an improvement.

6.1. Some Physics and Math behind a Piston (con’t 4)

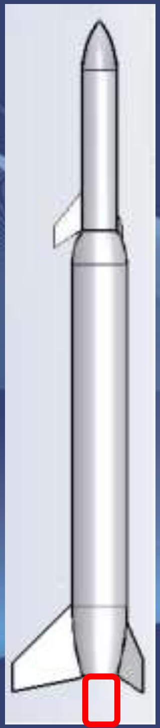
I do not encourage converting the ROCKET MODELLING competition into RIFLE-VERTICAL-SHOOTING competition. It will be a perversion of SPACEmodeling.

But to use efficiently what a rocket engine already has is a good idea.



Some ways for further piston improvement are described at the end of this («Piston») chapter.

6.2. Milestones of a Piston Launcher development



Robert H. GODDARD (USA)

Patented method of boosting the launch of a rocket by capturing the energy of exhaust gas

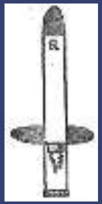
1940

ARCAS sounding rocket

Atlantic Research Corporation (USA) successfully applied the **closed breech launcher** to its ARCAS sounding rocket.

1959

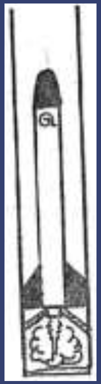
Wes WADA (Colorado Springs, USA)



First application of pressurization to the launching of model rockets

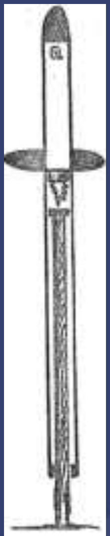
1963

Gordon K. MANDELL (USA)



Published plans for a **closed breech** launched model.

1969

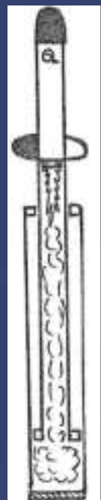


Geoff LANDIS (USA)

Invented the "**zero volume**" piston launcher

early 1970’s

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



George

HELSIER

(USA)

Invented «**Standard**» piston launcher

early 1970’s

Trip BARBER (USA)

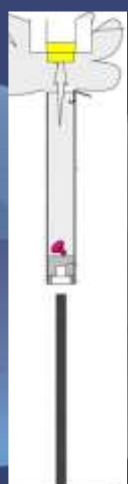
Laid out the basic physics of a piston launcher

1974

Howard KUHN (USA)

Made the first kit for a piston launcher.

late 1970’s

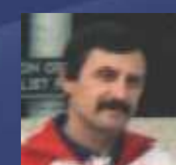


Chuck WEISS and **Jeff VINCENT**

(USA)

Introduced **Floating-Head** Piston

1986



Vladimir MINAKOV **Stanislav ZHIDKOV** **Victor KOVALEV** **Alexey KORIAPIN**

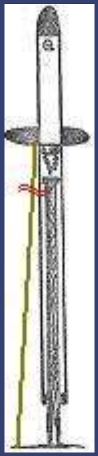
(USSR)

Russian/European style piston has been developed and applied at the FAI championships

1987

CM. NOTE

6.2. Milestones of a Piston Launcher development (con't 2)



Mikhail POTUPCHIK (RUSSIA, Miass, Chelyabinsk region)

Invented and Introduced «Behemoth» piston launcher with holding down by thread

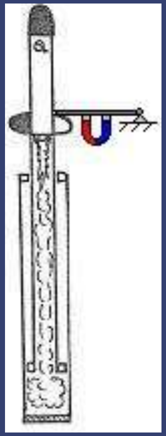
1995

Mikhail POTUPCHIK **Vladimir ISAEV** **Andrey SEMIENOV**

(RUSSIA, Miass, Chelyabinsk region)

Published schematics for **piston** launcher with **receiver chamber**

1996



Robert PARKS **Ryan COLEMAN**

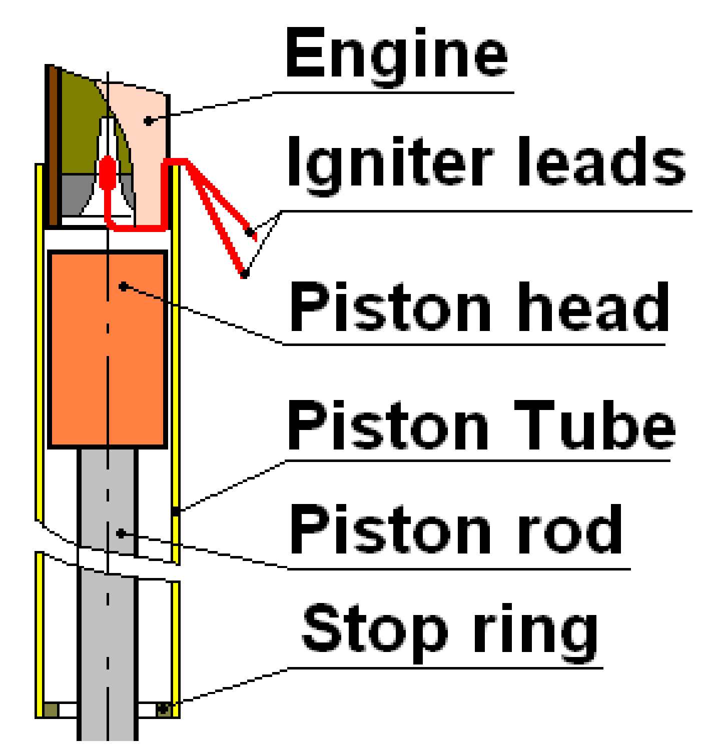
(USA)

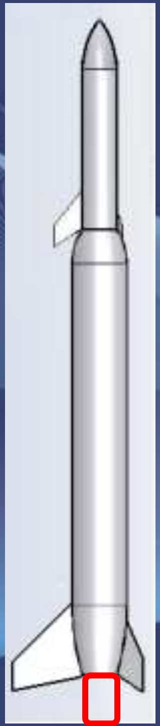
Introduced "**The Pacific Flying Machines** (PFM) **Piston**"

2010

CM. NOTE

6.3. Schematic of original “zero volume” US piston





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

MINAKOV Vladimir

ZHIDKOV Stanislav

KOVALEV Victor

KORIAPIN Alexey

Improvements made to the original US piston’s design:

1. Used more reliable and stronger (than paper) material for the piston tube – Fiberglass-Epoxy; Carbon-Epoxy; and later on – Kevlar-Epoxy; and/or combinations of the above.
2. Increased piston tube diameter (which provides the greater pushing force value).
3. Decreased engine-piston friction.
4. Relocated igniter leads (put inside of the Guiding Support Tube). Simplified pre-launch preparation, and the igniter insertion-connection. Increased reliability of engine ignition.

SEE NOTE

6.5. First results of Russian Piston application

1. 7th WCh-1987, Yugoslavia. S8.
   KOVALEV Victor - Gold medal

Podium S8 (L-R):
GASSAWAY George (USA) – 3rd
KOVALEV Victor (USSR) – 1st
RUSEV Svetozar (BUL) – 2nd

Victor KOVALEV and
George GASSAWAY

Victor KOVALEV R/C Rocket Glider
fitted to its piston launcher.

SEE NOTE

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

2. 2nd EuCh-1988, Romania. S5.
   MINAKOV Vladimir - Gold medal

MINAKOV

Vladimir

ILYIN

Sergei

Podium S5 :

Place	*Name*	*Nat*
1	MINAKOV Vladimir	USSR
2	KOTUHA Jan	TCH
3	ILYIN Sergei	USSR

MMR-06 scale model fitted to piston launcher.

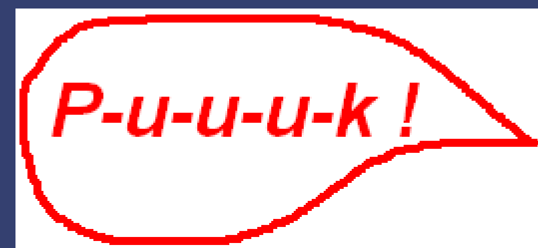
SEE NOTE

6.6. Russian Piston Name

“God father” of “Puk”

(Russian piston):

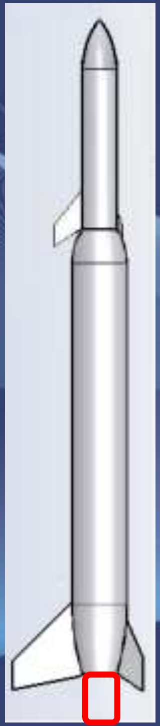
KUZMIN Victor

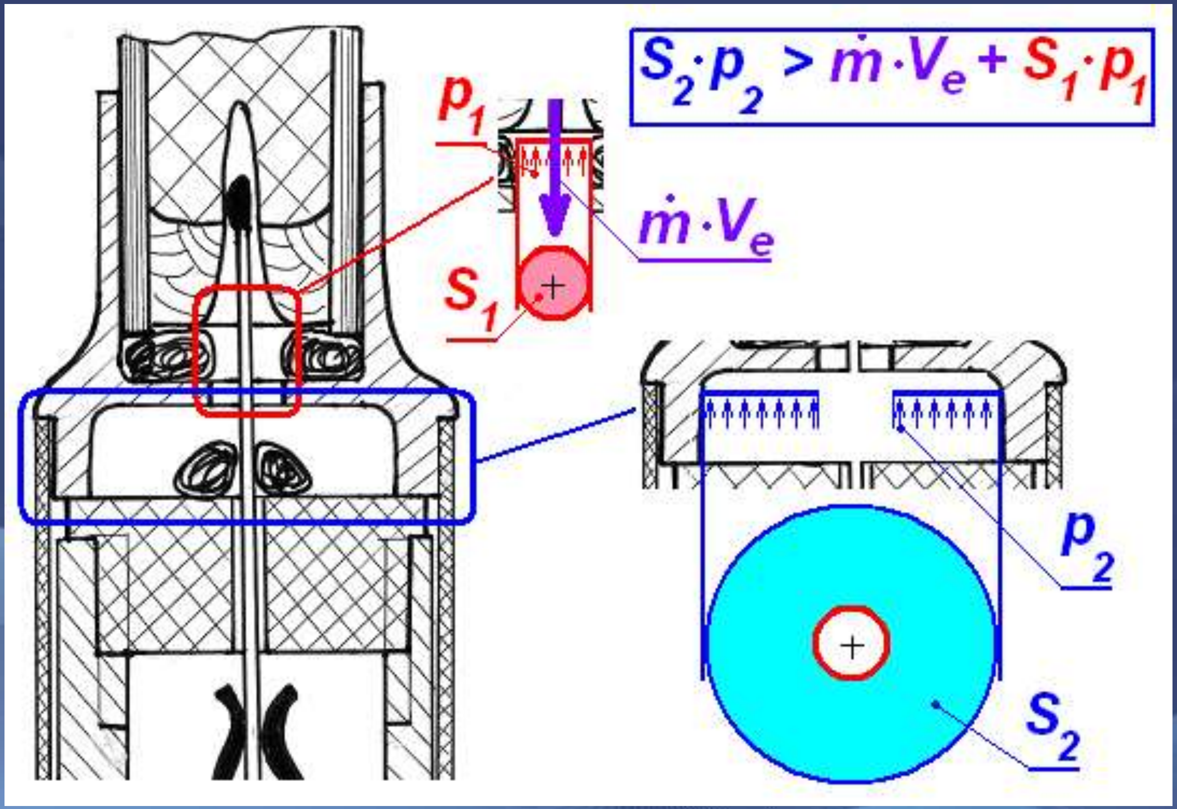


SEE NOTE

6.7. Comments on piston design

6.7.1. Engine - Piston Tube fitting

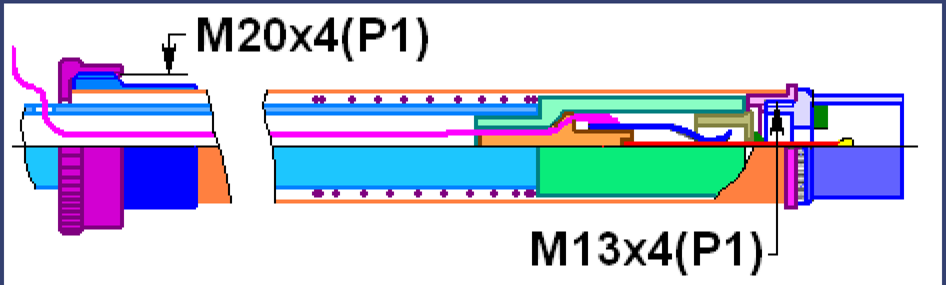




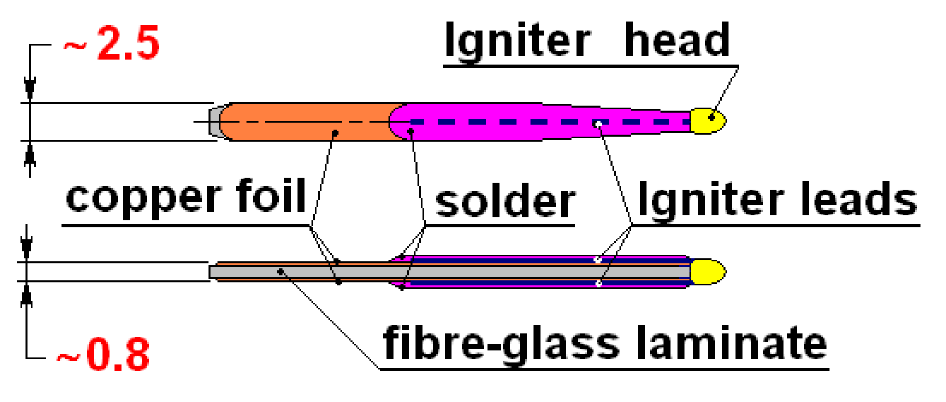
SEE NOTE

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

6.7.2. Quadruple threads.



6.7.3. Igniter.



6.7.4. Tube ID - Piston Head OD Gap.

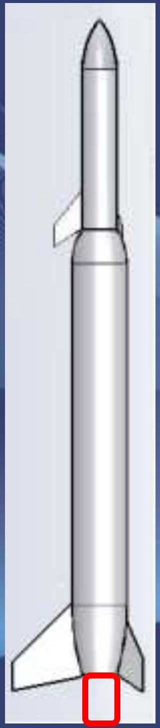
(Tube ID) - (Piston Head OD) ≈ 0.12 - 0.14 mm

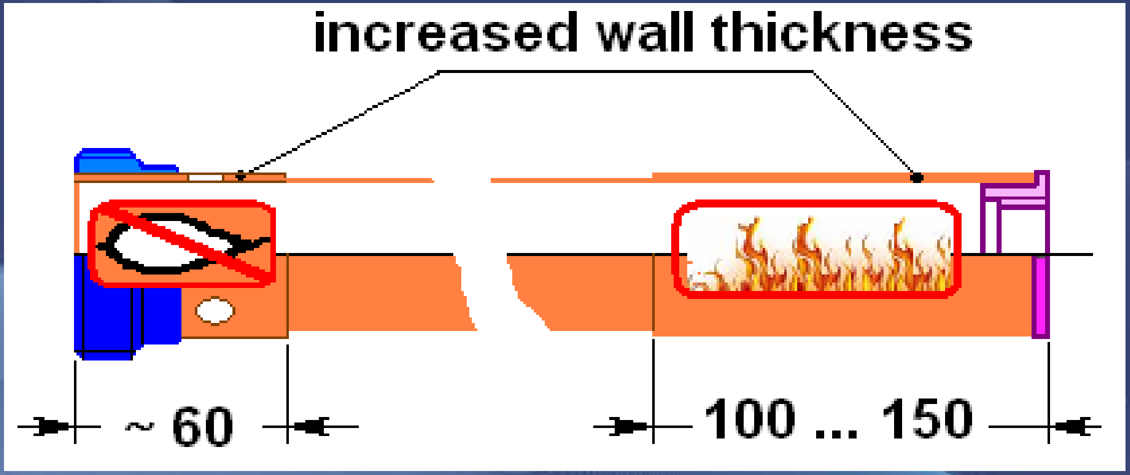
SEE NOTE

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

6.7.5. Tube's vent holes location.

6.7.6. Tube's wall thickness.

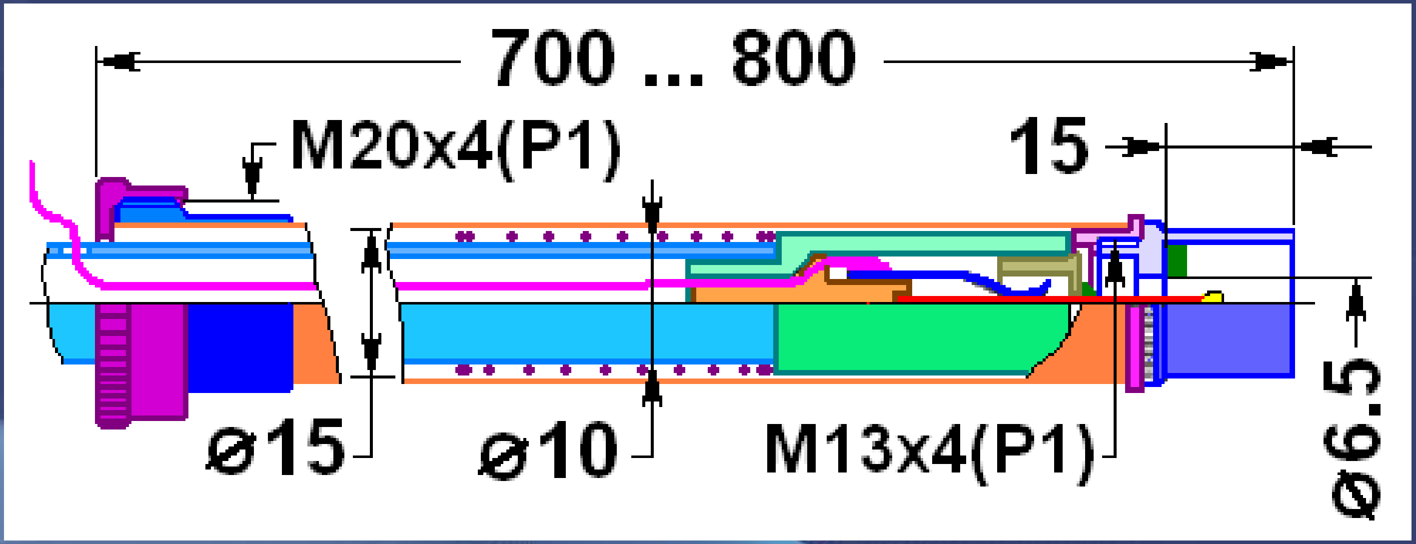


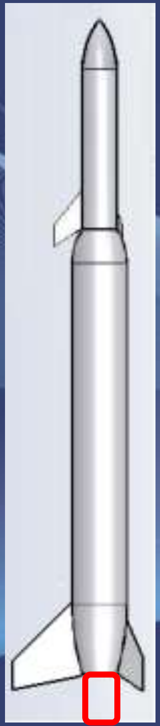


SEE NOTE

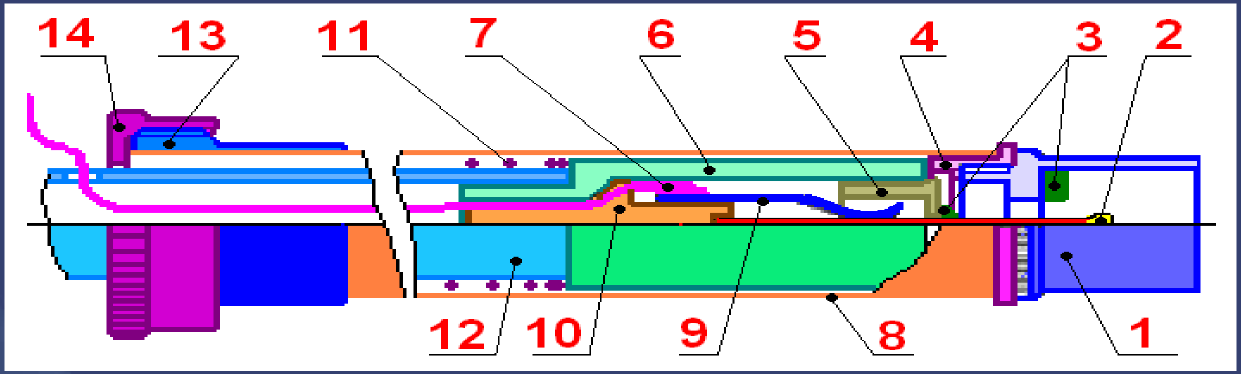
6.8. Basic dimensions

Piston for models S1 / S3 / S4 / S5 / S6 / S9:





6.9. Piston. BOM



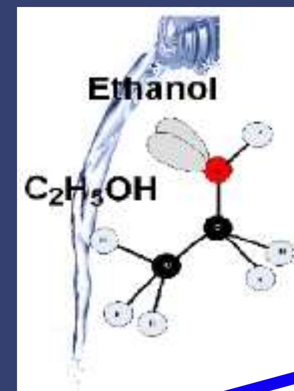
#	Part	Material	Comments	Approx, weight (for moving parts), g
1	Engine fitting Sleeve	duralumin	quadruple threaded	1.8
2	Ignitor	copper-clad fibre-glass-based laminate (Δ= 0.8 - 1.0 mm), with soldered standard igniter		
3	Silicone Sealant			0.2
4	Threaded Sleeve (top)	duralumin	quadruple threaded	0.8
5	Head Cover Cap	heat-resistant textolite		
6	Piston Head	stainless steel		
7	Ware			
8	Piston Tube	2 layers of fibre-glass (Δ= 0.06 mm) or 1 layer of Kevlar (Δ= 0.12 mm) - epoxy		10 - 15
9	Lamella	stainless steel spring strap	(Δ= 0.5 - 0.7 mm)	
10	Lamella mounting bushing	textolite		
11	Spring	high tensile steel wire	∅ 1 mm	
12	Guiding Support Tube	duralumin		
13	Threaded Sleeve (bottom)	duralumin	quadruple threaded	2.1
14	Stop Nut	duralumin	quadruple threaded	7.5
			Moving parts total weight, g	22 – 27

SEE NOTE

6.10. Piston Cleaning

Piston tubes should be cleaned and dried out after each and every flight. One of the best cleaning solutions is mixture of water and alcohol … i.e. VODKA

+



=

WSMC-1990. USSR, Kiev.
USSR team in S1.
L-R: Koriapin A., Mitiuriev A., Kuzmin V.

Piston cleaning with Stoli.

SEE NOTE

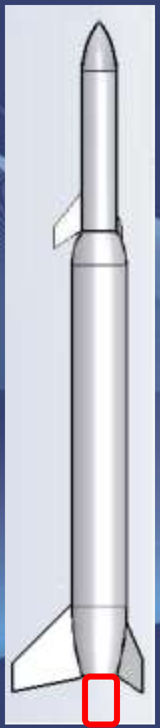
6.11. Further Piston Improvements

TBD

6.11.1. Combined Engine-Piston optimization.

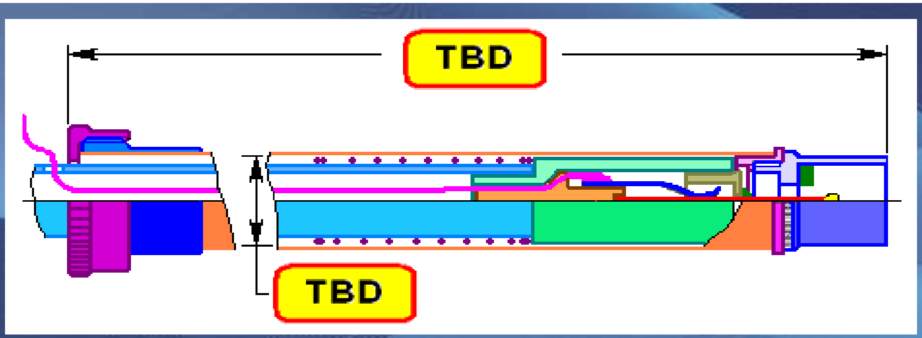
Reduce 1st stage engine burn time – and it will increase the portion of the engine's exhaust gases working inside of a piston.
See subchapter "5.1. 1st Stage Engines".

6.11. 2. Piston Tube diameter and length optimization.



Back in late 1980's when the basics of the current Russian piston design were established, piston Tube ID (both for S8 and S1/5 (S3/4/6)) were chosen on the basis of mandrel tubes availability:
ID 21-24 mm for S8 and ID 15 mm (diameter of ski poles)
At the same time, selection of tube ID also was driven by the empirical "Minakov's rule" – **Piston's Tube ID should be about 2 - 4 mm greater than Engine's OD.**

However, accurate and detailed R&D should be done in order to determine the range of optimal Piston Tube geometry.

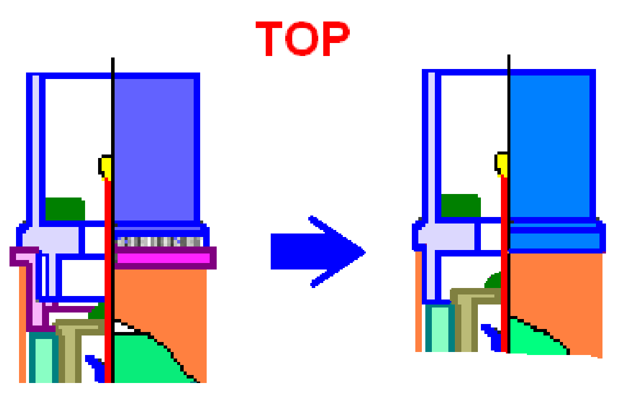


6.11.3. Reducing weight of Piston's moving parts

A. **Replace** relatively heavy **duralumin** (ρ = 2.8 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).

B. **Removing Threaded Sleeve (top)** – replace the Top fastening couple with Engine fitting Sleeve glued temporary into Piston Tube.

However, this change will result in reduced mobility, and inconvenience of piston parts assembling/disassembling for cleaning-launch preparation purposes.



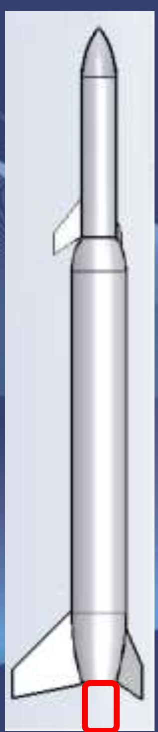
SEE NOTE

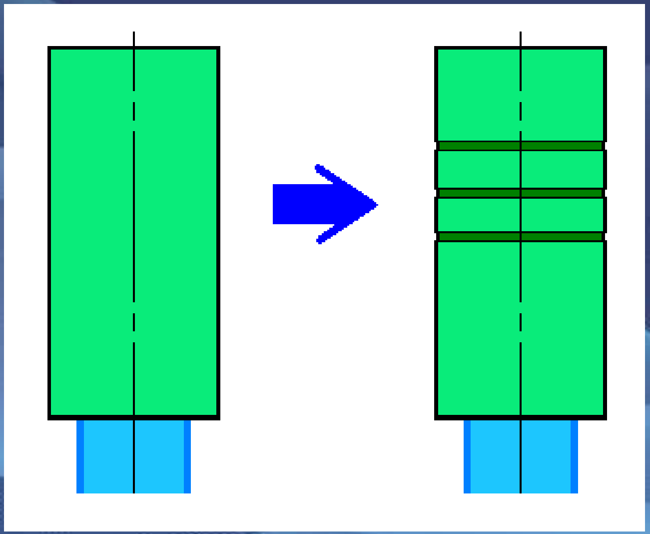
6.11.4. Reducing Piston Head –Tube exhaust gases leaks

This is very easy to achieve, and without even reducing the Piston Head – Tube gap, and without sequentially increasing the Piston Head –Tube friction.

Usually Piston Heads are bald.

Make a labyrinth seal, a row of 2-3 grooves on a surface of Piston Head. Exhaust gases leaks will be by an order of magnitude smaller.





6.11.5. Reducing friction "Piston Head –Tube" when moving and "Model – Piston" at separation

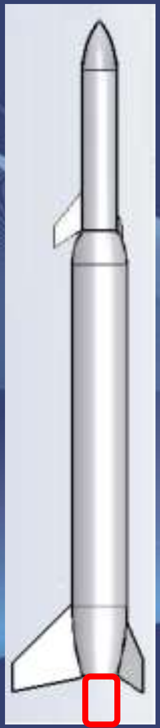
Possible ways to reduce friction:

- Use Teflon for the Piston Head and Engine Fitting Sleeve.

- Use lubricants, for example molybdenum disulphide.

Possible methods of lubricant embedding
- Use molynutz process (for metal parts).
- Impregnation of tubing's internal surface with powdered molybdenum disulphide during tube's fabrication/forming by dispersing powder onto epoxy-wetted fiber (Kevlar, carbon)-

to be- internal tube's surface.



6.11.6. Developing and improving new piston launcher devices

Developing and improving launch devices, which better utilize energy of the exhaust gases, specifically devices which holding

down the model and piston to build up pressure before first motion.

Example of this type launcher, PFM (of Robert Parks and Ryan Coleman) showed a significant improvement in the flight altitude (with accelerations of up to 90G (900 m/sec^2) at model-piston separation point) compare to the traditional Pistons ("Zero

Volume" and Floating Head pistons).

SEE NOTE

7. Streamer

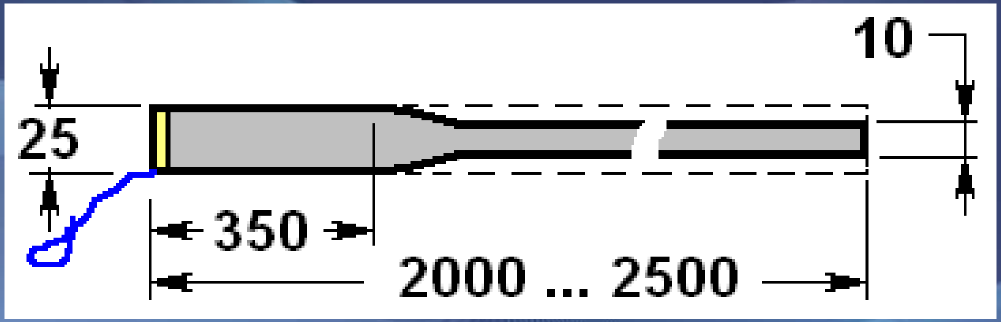
7.1. Material. Dimensions. Shape

A. Recommended material.

Metallised Mylar (polyethylene terephthalate),

thickness Δ = 10 … 12 mkm

B. Recommended shape and dimensions.



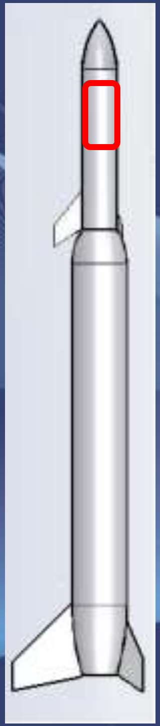
Weight reduction: from ~ 2.5 gram to ~ 1.2 gram

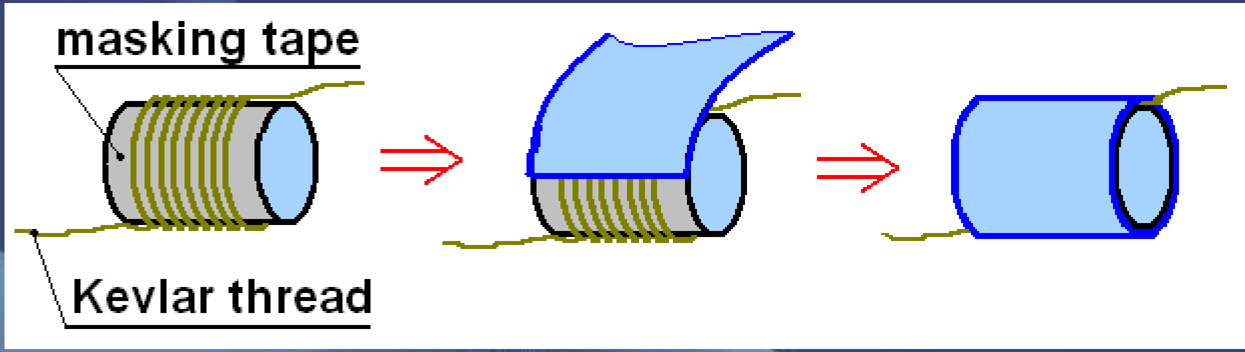
SEE NOTE

7.2. Body-NC-Streamer attaching

Ejection shock absorption.

Zero-rebound stroke shock-absorber:





Appl for S3/6/9

Appl for S5

SEE NOTE

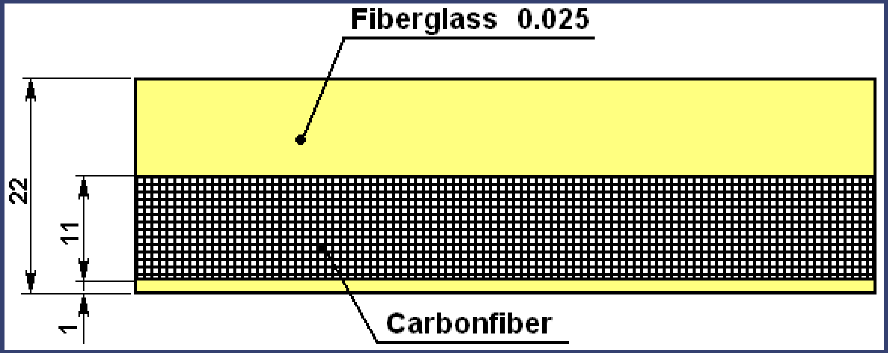
8. Reliability issues

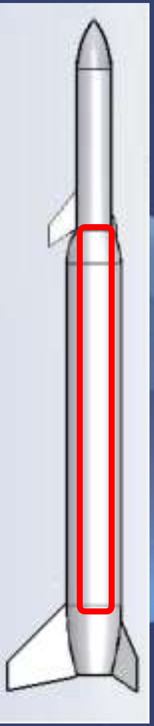
8.1. Ignition of 2nd Stage engine. Reliability improvement

8.1.1. Flash Tube.

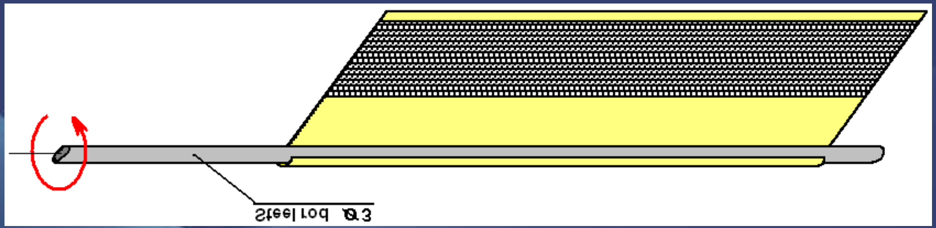
Fabrication of a Flash Tube.

Approximate dimensions and fiberglass / carbon fiber lay-out:



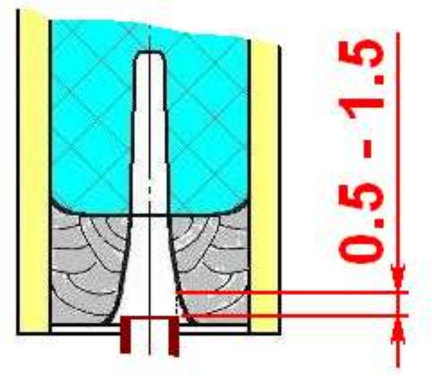


Flash Tube winding:



Carbon cloth thickness, mm	Tube ID / OD, mm	Tube weight per length, g / m
0.08	3 / ~ 3.25	~ 2.0
0.16	3 / ~ 3.5	~ 4.0

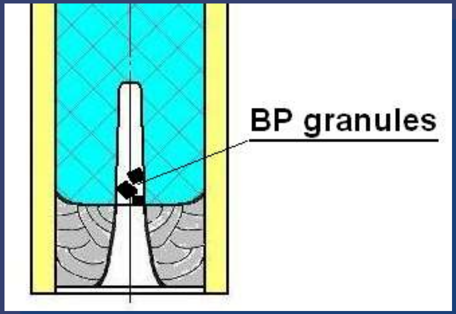
Gap between the top of the Flash Tube and the nozzle of the 2nd Stage engine:

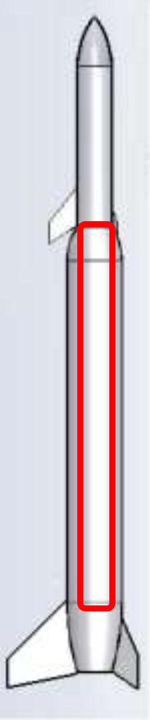


SEE NOTE

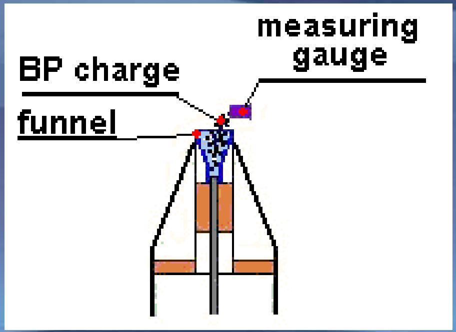
8.1. Ignition of 2nd Stage engine (con't)

8.1.2. Black Powder granules padding.





8.1.3. BP charge in a bottom stage engine.

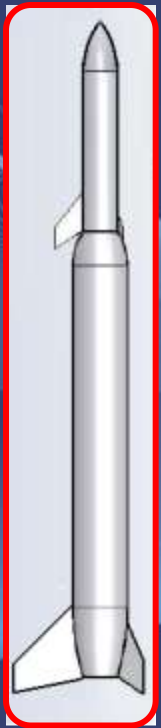


	Measuring gauge ID = 5.6 mm
Tube length, mm	Measuring gauge length, mm
~ 150	4
300 - 350	6

SEE NOTE

8.2. Testing

8.2.1. Ground Testing



8.2.2. Flight Testing.

- Flight Log Book

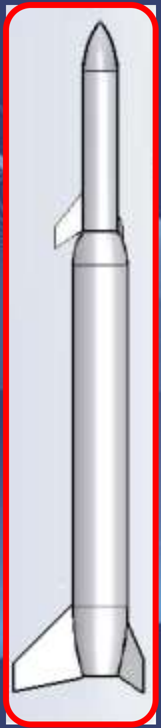
- Altimeters

SEE NOTE

8.2.3. Some recommendations for Flight Tests preparation and conduction

8.2.3.1. Flights number

- at least 3 flights for each compared option



8.2.3.2. Test models quality and uniformity

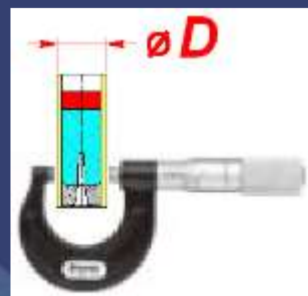
8.2.3.3. Weather conditions during testing

SEE NOTE

8.2.3. Some recommendations for Flight Tests preparation and conduction (con’t)

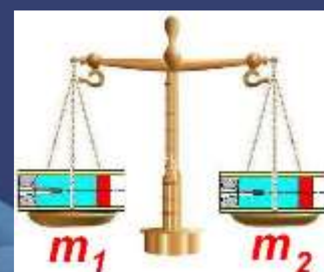
8.2.3.4. Engines selection for test flights

- Same batch

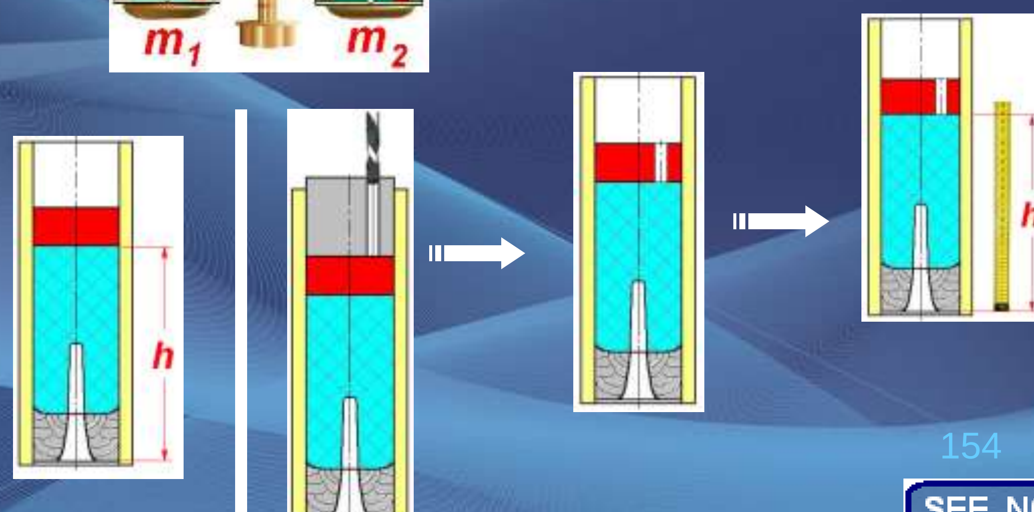


- Same OD

- Same weight



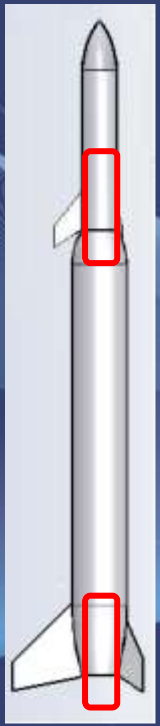
- Same «nozzle+propellant» charge height

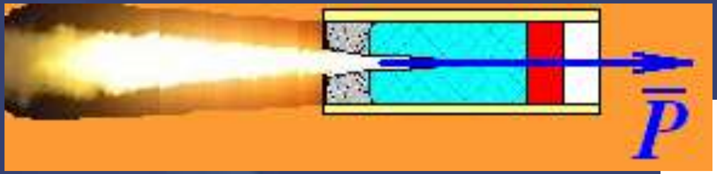


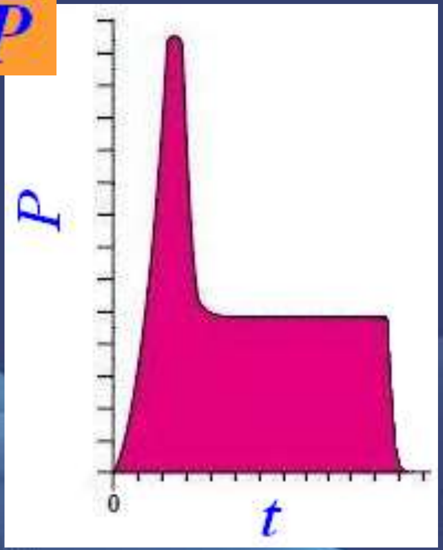
SEE NOTE

8.2.3.4. Engines selection for test flights (Con't)

- Engines Static Test







$\Rightarrow$ I_{Σ}

8.2.4. Second Stages Separate Flight Testing

Saving of the 1st stage engines

$ $ → min

Impact reduction of:

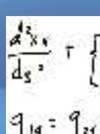
- spread in performance of the 1st stage engines;

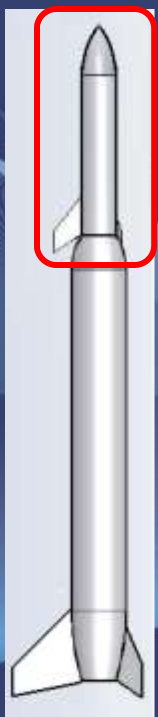
Δ  → 0

- spread in stages separation;

Δ  → 0

- errors in math models of the 1st stage flight

Δ  → 0

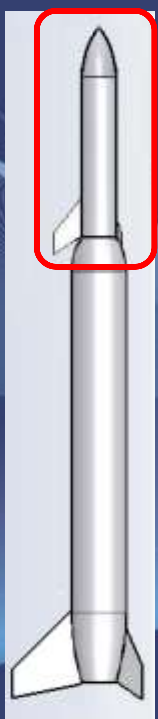


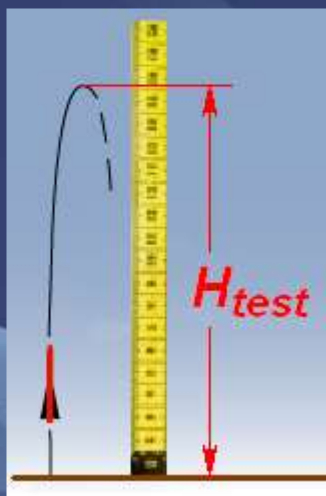
SEE NOTE

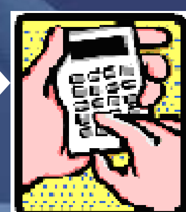
8.2.5. Flight Testing to determine body's airflow regime

8.2.5.1. Measured test flight altitude and calculated altitude COMPARISON

Test Flight

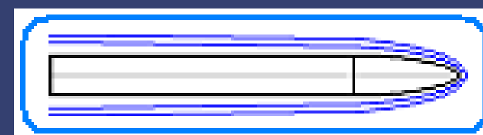


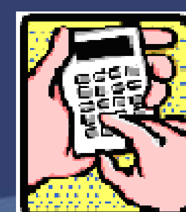




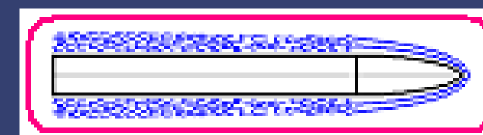
$Cd_{total\ aver}$ (test)

Numerical Analysis





$Cd_{total}(V_{aver})$ Laminar



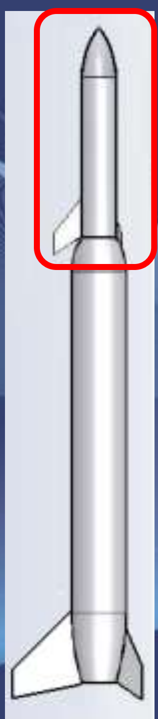
$Cd_{total}(V_{aver})$ Turbulent

?

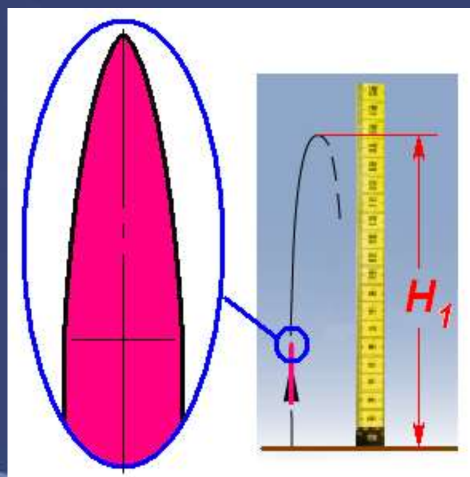
?

SEE NOTE

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

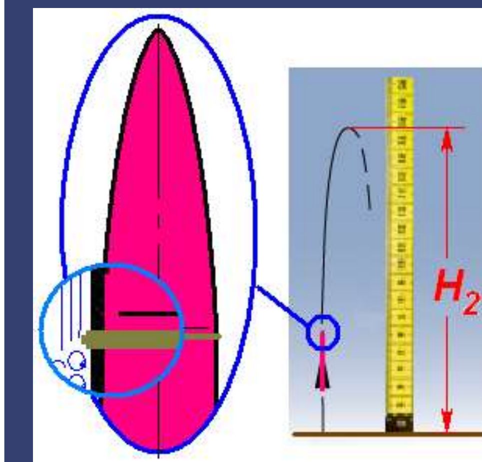


No turbulator:



H_1

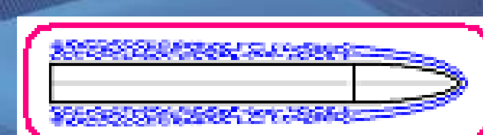
With turbulator:



H_2

$$(H_1 - H_2) / H_1 = ?$$

or



SEE NOTE

9. Technical results of the past World and European Championships (top 10 contenders)

6th WSMC-1985. Bulgaria, Yambol

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	KORIAPIN Alexey	USSR	730	778	753	778	0.0	
2	ILYIN Sergei	USSR	758	628	0	758	2.6	2.6
3	BARBER Arthur	USA	705	676	0	705	9.4	6.0
4	TABORSKY Jiri	CSSR	587	677	484	677	13.0	
5	JURECKY Z.	POL	660	575	520	660	15.2	
6	MITIURIEV Alexander	USSR	0	580	0	580	25.4	13.1
7	HOLUB Pavel	CSSR	469	535	566	566	27.2	
8	MARCHYN T.	CSSR	0	536	530	536	31.1	
9	VINCENT Jeff	USA	485	507	513	513	34.1	
10	STANKOVIC S.	YUG	496	498	364	498	36.0	21.6

FAI Code technical requirements for S1:

- **Minimum diameter** 18 mm for at least of 50% of the overall length.
- **No** requirements for **minimum overall length**.
- **No** requirements for **division** of engines **Total Impulse** between stages.

7th WSMC-1987 Yugoslavia, Belgrade

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	CUDEN Marjan	YUG	758	948	843	948	0.0	
2	STEMPIHAR Bogo	YUG	919	843	943	943	0.5	0.5
3	STANCEVIC Miroslav	YUG	763	851	703	851	10.2	5.4
4	STEELE Matt	USA	612	0	844	844	11.0	
5	TABORSKY Jiri	TCH	623	761	771	771	18.7	
6	MITIURIEV Alexander	USSR	743	0	752	752	20.7	12.2
7	ILYIN Sergei	USSR	743	732	671	743	21.6	
8	VINCENT Jeff	USA	728	0	678	728	23.2	
9	WEISS Charles	USA	0	662	721	721	23.9	
10	ZYCH Robert	TCH	565	696	610	696	26.6	17.4

8th WSMC-1990 USSR, Kiev

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	KORIAPIN Alexey	URS	784	0	0	784	0.0	
2	MITIURIEV Alexander	URS	754	661	0	754	3.8	3.8
3	SPASOV MARINOV Djul	BUL	672	0	0	672	14.3	9.1
4	ZYCH Robert	TCH	656	0	0	656	16.3	
5	DRAGOV Tasko	BUL	0	608	0	608	22.4	
6	KOTUHA Jan	TCH	556	0	0	556	29.1	17.2
7	CUDEN Joze	YUG	536	0	0	536	31.6	
8	ROSE Arthur	USA	0	479	0	479	38.9	
9	SORNOVSKY P.	POL	0	454	0	454	42.1	
10	KRIGER M.	POL	359	314	450	450	42.6	26.8

FAI Code technical requirements for S1:

- **Minimum diameter** of 30 mm of enclosed airframe for at least 50 % of the overall body length.
- **Minimum overall body length**: at least 350 mm.

9th WSMC-1992 USA, Melbourne, FL

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	VINCENT Jeff	USA	794	948	TL	948	0.0	
2	ILYIN Sergei	RUS	TL	787		787	17.0	17.0
2	MITIURIEV Alexander	RUS	787	784	787	787	17.0	17.0
4	KOTUHA Jan	TCH	TL	772	TL	772	18.6	
5	KUZMIN Viktor	RUS	704	TL		704	25.7	
6	VOLKANOV Igor	UKR	DQ	DQ	615	615	35.1	22.7
7	LVOVYCH Valeriy	UKR	308	584	DQ	584	38.4	
8	KOLAR Zdenek	TCH	571	NC		571	39.8	
9	ROURA J.	SPAIN	506	TL	449	506	46.6	
10	MISSE M.	SPAIN	473	NC	475	475	49.9	32.0

4th EuSMC-1993 Romania, Suceava

Place	Competitor	Country	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	MITIURIEV Alexander	RUS	1178	0.0	
2	HAPON Juri	UKR	966	18.0	18.0
3	VOLKANOV Igor	UKR	829	29.6	23.8
4	ZYCH Robert	TCH	823	30.1	
5	LVOVYCH Valeriy	UKR	812	31.1	
6	ZARAKAUSKIS Vilnis	LAT	784	33.4	28.5
7	KORIAPIN Alexey	RUS	768	34.8	

10th WSMC-1994 Poland, Leszno

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	KORIAPIN Alexey	RUS	242	624	0	624	0.0	
2	JIAN Li	CHN	0	0	597	597	4.3	4.3
3	CUDEN Marjan	SLO	377	354	577	577	7.5	5.9
4	SZUMSKY Boleslaw	POL	365	0	573	573	8.2	
5	OPOCZKA Antoni	POL	552	269	0	552	11.5	
6	FRIEDEL Ingo	GER	0	528	0	528	15.4	9.4
7	VOLKANOV Igor	UKR	524	0	0	524	16.0	
8	BEDRICH Pavka	CZE	396	389	518	518	17.0	
9	LVOVYCH Valeriy	UKR	0	0	492	492	21.2	
10	MIANGUI Cheng	CHN	0	416	481	481	22.9	13.8

5th EuSMC-1995 Slovakia, Liptovsky Mikulas

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	VORONOV Oleg	RUS	1002	TL	TL	1002	0.0	
2	ZARAKAUSKIS Vilnis	LAT	448	913	DQ	913	8.9	8.9
3	KORIAPIN Alexey	RUS	TL	888	TL	888	11.4	10.1
4	MAZZARACCHIO Antonio	ITA		880	NC	880	12.2	
5	KOTUHA Miroslav	SVK	748	872	TL	872	13.0	
6	CUDEN Marjan	SLO		NC	829	829	17.3	12.5
7	MAZZARACCHIO Antonio	ITA	TL	827	TL	827	17.5	
8	HAPON Yuri	UKR	769	DQ		769	23.3	
9	FERBAS Josef	CZE	765	TL	TL	765	23.7	
10	ZITNAN Michal	SVK	650	DQ	NC	650	35.1	18.0

11^{h} WSMC-1996 Slovenia, Ljubljana

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	VORONOV Oleg	RUS	1209	0	0	1209	0.0	
2	KREUTZ Robert	USA	891.1	943	0	943	22.0	22.0
3	KORIAPIN Alexey	RUS	0	925	0	925	23.5	22.7
4	MAZZARACCHIO Antonio	ITA	0	904	0	904	25.2	
5	BEDRICH Pavka	CZE	384	856	0	856	29.2	
6	KOTUHA Jan	SVK	0	775	0	775	35.9	27.2
7	CUDEN Marjan	SLO	0	773	0	773	36.1	
8	KRAUZE Marian	GER	0	768	0	768	36.5	
9	KONSTANTINOVISC Edgars	LAT	752.5	0	0	752	37.8	
10	PAVLJUK Vasil	SVK	750.3		0	750	38.0	31.6

FAI Code technical requirements for S1:

Upper stage must have **diameter** of at least 18 mm**.**
No requirements for the location and the length of this (OD ≥ 18 mm) portion of the body.

6th EuSMC-1997 Turkey, Golbasi – Ankara (1st World AirGames)

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	VORONOV Oleg	RUS	0	1082	0	1082	0.0	
2	KORIAPIN Alexey	RUS	866	893	1071	1071	1.0	1.0
3	CUDEN Marjan	SLO	990	1064	0	1064	1.7	1.3
4	MENSHIKOV Vladimir	RUS	1044	1007	944	1044	3.5	
5	STEPANOV Maxim	RUS	0	939	1013	1013	6.4	
6	MAZZARACCHIO Antonio	ITA	0	1004	0	1004	7.2	4.0
7	PETROVIC Stanisa	MAC	661	0	903	903	16.5	
8	ŠIJANEC Anton	SLO	858	899	0	899	16.9	
9	KOGEJ Tomaz	SLO	844	880	0	880	18.7	
10	VOLKANOV Igor	UKR	645	833	0	833	23.0	10.5

FAI Code technical requirements for S1:

Upper stage must have **minimum diameter** 18 mm for at least of 50% of it's body length.

12^{h} WSMC-1998 Romania, Suceava

Place	Competitor	Country	Round 1	Round 2	Best Flight	Δ margin from 1st pl, %
1	MENSIKOV Vladimir	RUS	TL	622	622	0.0
2	CATARGIU Ioan	ROM	447		447	28.1
3	KATANIC Zoran	YUG	384	439	439	29.4
4	VORONOV Oleg	RUS	TL	414	414	33.4
5	PRIHOTIN Antonel	ROM	TL	410	410	34.1
6	TABORSKY Jiri	CZE		405	405	34.9
7	KONSTANTINOVISC Ed	LAT	392		392	37.0
8	KOTUHA Miroslav	SVK	367		367	41.0
9	CZAIKA Maciey	POL	349		349	43.9
10	LASOCHA Slawomir	POL	TL	341	341	45.2

FAI Code technical requirements for S1:

- **Total impulse of engine in a lower stage** must be equal or greater than total impulse of engine of upper stage.
- **No boat tail** for upper stage**.**

13th WSMC-2000 Slovakia, Liptovsky Mikulas

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	CUDEN Joze	SLO	-	710	DQ	710	0.0	
2	KUCZEK Kevin	USA	237	541	674	674	5.1	5.1
3	MAZZARACCHIO Antonio	ITA	673	DQ	-	673	5.2	5.1
4	MENSHIKOV Vladimir	RUS	579	604	670	670	5.6	
5	STEPANOV Maxim	RUS	666	635	NC	666	6.2	
6	HIRONAKA Ross	USA	-	653	665	665	6.3	5.7
7	O'BRYAN David	USA	NC	611	661	661	6.9	
8	VORONOV Oleg	RUS	NC	659	DQ	659	7.2	
9	KORIAPIN Alexey	RUS	645	NC	657	657	7.5	
10	KOTUHA Miroslav	SVK	-	529	636	636	10.4	6.7

14th WSMC-2002 Czech Republic, Sazena

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	ŠIJANEC Anton	SLO	TL		490	490	0.0	
2	ANDONOV Lazo	MKD	236	DQ	477	477	2.7	2.7
3	KOGEJ Tomaz	SLO	456	470	411	470	4.1	3.4
4	KRČEDINAC Radovan	YUG	318	454	DQ	454	7.3	
5	MALMYGA Leszek	POL	418	TL	DQ	418	14.7	
6	IWAI	JPN	DQ	381	DQ	381	22.2	10.2
7	BŨCHEL Jonas	GER		DQ	378	378	22.9	
8	KATANIĆ Radojica	YUG	307	TL	378	378	22.9	
9	BEDRICH Pavka	CZE	TL	DQ	375	375	23.5	
10	GIRA Tibor	SVK	247	375	231	375	23.5	16.0

FAI Code technical requirements for S1:

- **Minimum diameter** (of enclosed airframe for at least 50 % of the overall body length) was changed from 30mm to 40mm.
- **Minimum overall length** was changed from 350mm to 500mm.

9th EuSMC-2003 Serbia, Sremska Mitrovica

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	ŠIJANEC Anton	SLO	TL	NC	507	507	0.0	
2	GALOVIC Marek	SVK	DQ	TL	451	451	11.0	11.0
3	MATUSKA Peter	SVK	425	NC	-	425	16.2	13.6
4	MALMYGA Leszek	POL	DQ	418	NC,NC	418	17.6	
5	KORIAPIN Alexey	RUS	404	DQ	415	415	18.1	
6	KOGEJ Tomaz	SLO	411	NC,NC	0	411	18.9	16.4
7	CHALUPA Jaromir	CZE	386	403	NC	403	20.5	
8	BRONY Pavel	CZE	335	294	TL	335	33.9	
9	BEDRICH Pavka	CZE	381	372	281	381	24.9	
10	BONIECKI Jerzy	POL	CE,TL	191	367	367	27.6	21.0

15th WSMC-2004 Poland, Deblin

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	MAZZARACCHIO Antonio	ITA	534	657.5		657.5	0.0	
2	VORONOV Oleg	RUS	546	TL	653	653	0.7	0.7
3	MENSHIKOV Vladimir	RUS	629.5	TL	562	629.5	4.3	2.5
4	SIJANEC Anton	SLO	587.5	544	408	587.5	10.6	
5	KORIAPIN Alexey	RUS	DQ	TL	533,5	533.5	18.9	
6	MAŁMYGA Leszek	POL	530	DQ	DQ	530	19.4	10.8
7	CUDEN Joze	SLO	TL	527	DQ	527	19.8	
8	KATANIC Radojica	SCG	512.5	514	520.5	520.5	20.8	
9	JEVTIC Dragan	SCG	510	496	DQ	510	22.4	
10	WATANABE Toshiaki	JPN	DQ	DQ	504.5	504.5	23.3	15.6

10th EuSMC-2005 Romania, Buzau

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	VORONOV Oleg	RUS	TL	TL	675	675	0.0	
2	SIJANEC Anton	SLO	TL	514	664	664	1.6	1.6
3	KATANIC Radojica	SCG	547	TL	581	581	13.9	7.8
4	KORIAPIN Alexey	RUS	488	TL	575	575	14.8	
5	MALMYGA Leszek	POL	557	TL	531	557	17.5	
6	MAZZARACCHIO Antonio	ITA	550	DQ	DQ	550	18.5	13.3
7	RADOVAN Krecedinac	SCG	TL	548	491	548	18.8	
8	CUDEN Joze	SLO	536	DQ	519	536	20.6	
9	BEDRICH Pavka	CZE	502	486	525	525	22.2	
10	BRONY Pavel	CZE	TL	390	422	522	22.7	16.7

FAI Code technical requirements for S1:

The **smallest body diameter** must be not less than 18 mm for at least 75% of the overall length of each stage.

16h WSMC-2006 Russia / Kazakhstan, Baikonur

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	MENSHIKOV Vladimir	RUS	588	612	D.Q.	612	0.0	
2	ROMANIOUK Sergei	RUS	601	569	561	601	1.8	1.8
3	KRČEDINAC Branislav	SRB	---	575	D.Q.	575	6.0	3.9
3	ČUDEN Jože	SLO	---	D.Q.	575	575	6.0	
5	RESHETNIKOV Alexey	RUS	D.Q.	534	567	567	7.4	
6	MAZZARACCHIO Antonio	ITA	520	534	466	534	12.7	6.8
7	KATANIĆ Zoran	SRB	---	491	529	529	13.6	
8	MALMYGA Leszek	POL	496	508	482	508	17.0	
9	KATANIĆ Radojica	SRB	---	486	500	500	18.3	
10	KOGEJ Tomaž	SLO	TL	D.Q.	494	494	19.3	11.3

12th EuSMC-2009 Serbia, Irig

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	CHMELIK Jaroslav	CZE	DQ	621	NC	621	0.0	
2	CUDEN Joze	SLO	0	621	TL	621	0.0	0.0
3	JAVORIK Milan	SVK	400	619	583	619	0.3	0.2
4	STOYANOV Toshko	BUL	NC	582	403	582	6.3	
5	MAZZARACCHIO Antonio	ITA	DQ	517	573	573	7.7	
6	ROMANYUK Sergey	RUS	530	DQ	TL	530	14.7	5.8
7	KRAUSE Marian	ROU	DQ	524	0	524	15.6	
8	ČIPČIĆ Vladimir	SRB	DQ	TL, 512	0	512	17.6	
9	MALMYGA Leszek	POL	DQ	507	TL, TL	507	18.4	
10	PETROVIĆ Staniša	MKD	NC	DQ	507	507	18.4	11.0

18^{h} WSMC-2010 Serbia, Irig

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	ČUDEN Jože	SLO	698		0	698	0.0	
2	ČUDEN Miha	SLO	663		0	663	5.0	5.0
3	KRASNOV Pavel	RUS	540	632	657	657	5.9	5.4
4	ROMANYUK Sergey	RUS	649		641	649	7.0	
5	RESHETNIKOV Alexey	RUS	581	644	0	644	7.7	
6	MAZZARACCHIO Antonio	ITA	604	638	640	640	8.3	6.8
7	MENSHIKOV Vladimir	RUS	635		0	635	9.0	
8	ŠIJANEC Anton	SLO	622	0	606	622	10.9	
9	KRČEDINAC Mladen	SRB		536	587	587	15.9	
10	KATANIĆ Zoran	SRB	574			574	17.8	9.7

13th EuSMC-2011 Romania, Buzau

Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
1	MENSHIKOV Vladimir	RUS	0	617	666	666	0.0	
2	CUDEN Joze	SLO	0	659	0	659	1.1	1.1
3	KRASNOV Pavel	RUS	642	564	624	642	3.6	2.3
4	SERCAIANU Florica	ROM	0	620	0	620	6.9	
5	ROMANYUK Sergey	RUS	601	614	591	614	7.8	
6	TIMOFEJEV Maksim	LTU	0	600	0	600	9.9	5.9
7	SERCAIANU Lucian	ROM	542	568	588	588	11.7	
8	KRCEDINAC Branislav	SRB	0	574	556	574	13.8	
9	SIJANEC Anton	SLO	0	568	0	568	14.7	
10	CUDEN Miha	SLO	0	568	0	568	14.7	9.4

19th WSMC-2000 Slovakia, Liptovsky Mikulas

	Place	Competitor	Country	Round 1	Round 2	Round 3	Best Flight	Δ margin from 1st pl, %	Aver margin from 1st, %
790	1	TIMOFEJEV Maksim	LTU	790	-	-	790	0.0	
790	2	TREIKAUSKAS Mykolas	LTU	-	746	702	746	5.6	5.6
790	3	KATANIC Zoran	SRB	709	674	-	709	10.3	7.9
790	4	KRCEDINAC Branislav	SRB	693	624	611	693	12.3	
790	5	CIPCIC Vladimir	SRB	682	665	582	682	13.7	
790	6	CUDEN Miha	SLO	672	-	643	672	14.9	11.3
790	7	CUDEN Joze	SLO	670	-	660	670	15.2	
790	8	MALMYGA Leszek	POL	543	638	618	638	19.2	
790	9	ROMANYUK Sergey	RUS	NC	DQ	634	634	19.7	
790	10	KREUTZ Robert	USA	632	461	-	632	20.0	14.5

10. Key success factors of the past World Championships title-holders

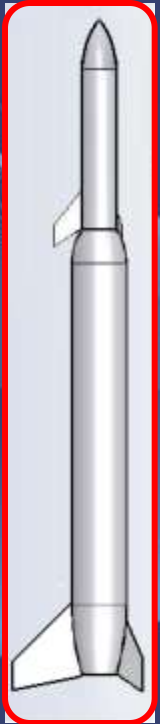
SEE NOTE

10.1. WSMC-1985. Gold medal - KORIAPIN Alexey (USSR)

Podium S1A (L-R):

ILYIN Sergei (USSR) – 2nd
KORIAPIN Alexey (USSR) – 1st
BARBER Trip (USA) – 3rd

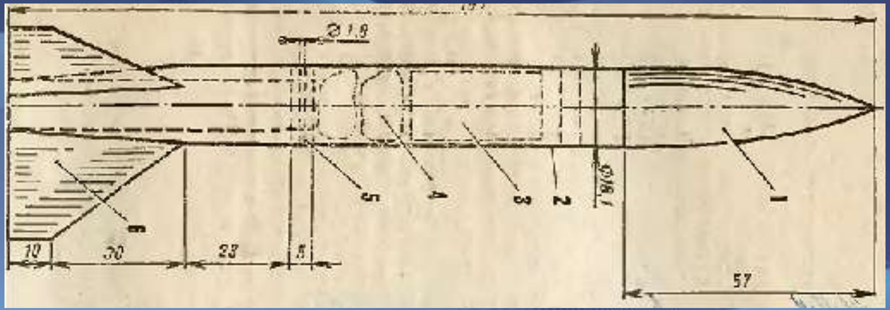
Key winning factors:



1. Very good engines (Anatoly Sparish design & manufacturing):

   BP; total Impulse - just under “red line” - I_{Σ} = 4.85 - 4.9 N · sec;
   with great for BP value of $I_{sp} \approx$ 950 N · sec / kg

2. Intelligent model design



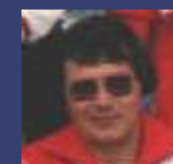
3. Preparedness for competition; readiness during models preparation for flights – was able to launch all 3 tractable flights.

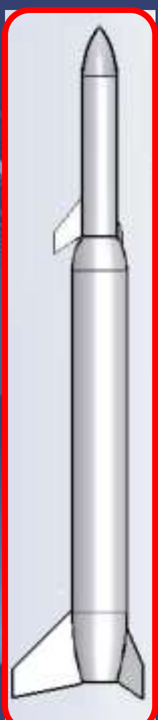
10.2. WSMC-1990. Gold medal - KORIAPIN Alexey (USSR)

Podium S1A (L-R):

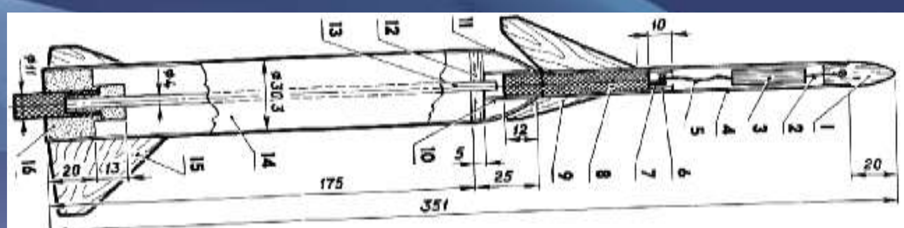
MITIURIEV Alexander (USSR) – 2^{nd}
KORIAPIN Alexey (USSR) – 1^{st}
SPASOV MARINOV Djulijan (BUL) – 3^{rd}

Key winning factors:



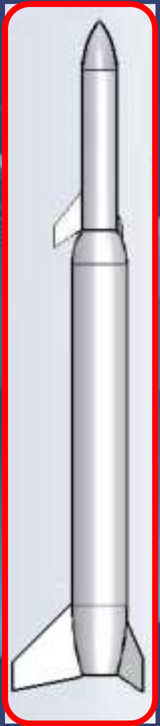


1. Very good engines (Anatoly Sparish design & manufacturing):
2. Uneven total impulse for stages:
   I_{Σ} = 1.25 N · sec (1^{st} stage) + 3.75 N · sec (2^{nd} stage)
   - 2^{nd} stage - compound, specific impulse $I_{sp} \approx 1200$ N · sec / kg
3. Intelligent model design



4. Preparedness for competition. Composure.
5. Readiness. Ready to launch at very beginning of competition when weather – sky condition – visibility/tractability were the best.

10.3. WSMC-1992. Gold medal - VINCENT Jeff (USA)



Podium S1A (L-R):

ILYIN Sergei (RUS) – 2nd
VINCENT Jeff (USA) – 1st
MITIURIEV Alexander (RUS) – 2nd

Key winning factors:

1. Very good engine for 2nd stage (Jiri Taborsky's "Delta" 3/4 B): compound, specific impulse $I_{sp} \approx 1200$ N · sec / kg

2. Uneven total impulse for stages:
   $I_{\Sigma} = 1.25$ N · sec (1st stage, engine: Estes 13mm 1/2A3)
   + 3.75 N · sec (2nd stage)

3. Intelligent model design.
   Reduced 2nd stage drag by means of, inter alia:
   - Thin "waferglass" fins;
   - Long NC (length-diameter ratio λ= 3).

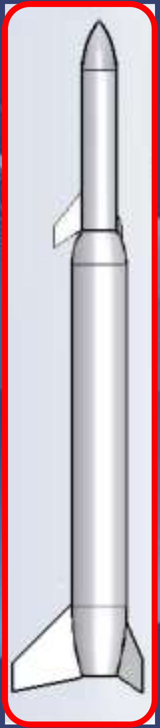
10.4. WSMC-1994. Gold medal - KORIAPIN Alexey (Russia)

Podium S1A (L-R):

JIAN Li (CHN) – 2nd
KORIAPIN Alexey (RUS) – 1st
CUDEN Marjan (SLO) – 3rd

Key winning factors:

1. Very good and reliable engines (Anatoly Sparish design & manufacturing).
2. Absolute **PREPAREDNESS** for the competition.
3. Composure and readiness.
4. Situation awareness (about weather condition: in general and what is coming, what is going on – sky condition – visibility/tractability).
5. **Flexibility during competition**.
   Changed engines combination from 1.25 / 3.75 (N · sec) to 1.25 / 2.5 (N · sec) at poor sky visibility and was ready to launch when the best "window" in clouds with clear blue sky came to (and not from launch spot, but when visibility is best from tracing stations points of view).
6. Model design – similar to design-1990 (see previous slide).



Despite to the fact that Alexey's models were designed and built for performance for best weather conditions, he was able to compromise and perform great even under not great conditions.

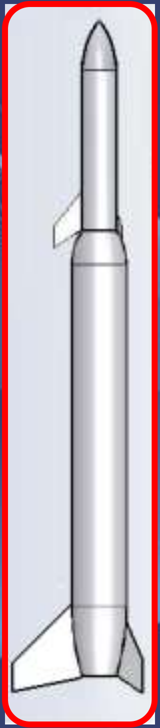
10.5. WSMC-1996. Gold medal - VORONOV Oleg (Russia)

Podium S1A (L-R):
KREUTZ Robert (USA) – 2nd
VORONOV Oleg (RUS) – 1st
KORIAPIN Alexey (RUS) – 3rd

Key winning factors:

1. Very good engines (Jiri Taborsky's "Delta"):
   Uneven total impulse for stages: $I_{\Sigma} = 0.6$ N · sec (1st stage) + 4.4 N · sec (2nd stage)
   1st and 2nd stage – "compound", specific Impulse $I_{sp} \approx 1200$ N · sec / kg.

2. Very intelligent model design.
   Reduced 2nd stage drag by means of, inter alia:
   - Smooth NC-Body juncture;
   - Thin ($\delta = 0.24$ mm) carbon fins;
   - Fins with rounded leading edge and sharp-pointed trailing edge (wedge width of ~ 3 mm);
   - Body-fins fillet. $R_{fillet} \approx 1.2$ mm;
   - Long NC (length-diameter ratio $\lambda = 4$, greater than anybody's else).



Approximate image of O. Voronov's S1 model:

V. Menshikov's S1 model (1996)

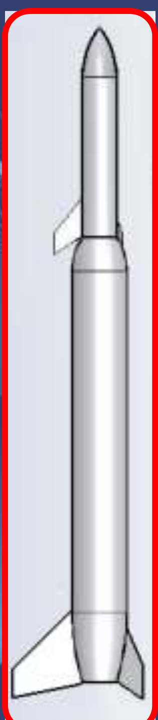
3. Preparedness for competition. Composure.

10.6. WSMC-1998. Gold medal - MENSHIKOV Vladimir (Russia)

Podium S1A:

Place	*Name*	*Nat*
1	MENSHIKOV Vladimir	RUS
2	CATARGIU Ion	ROU
3	KATANIC Zoran	YUG

Key winning factors:



1. Very good engines:
   J. Taborsky's "Delta". 1st and 2nd stage – "compound", specific Impulse $I_{sp} \approx 1200$ N · sec / kg.

2. Intelligent model design.

3. Preparedness for competition; composure and readiness during models preparation.

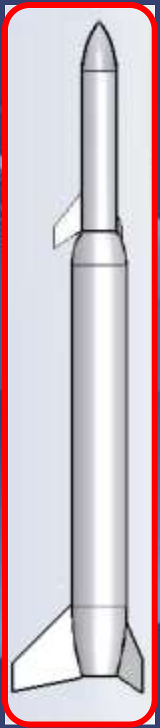
10.7. WSMC-2004. Gold medal - MAZZARACCHIO Antonio (Italy)

Podium S1A (L-R):

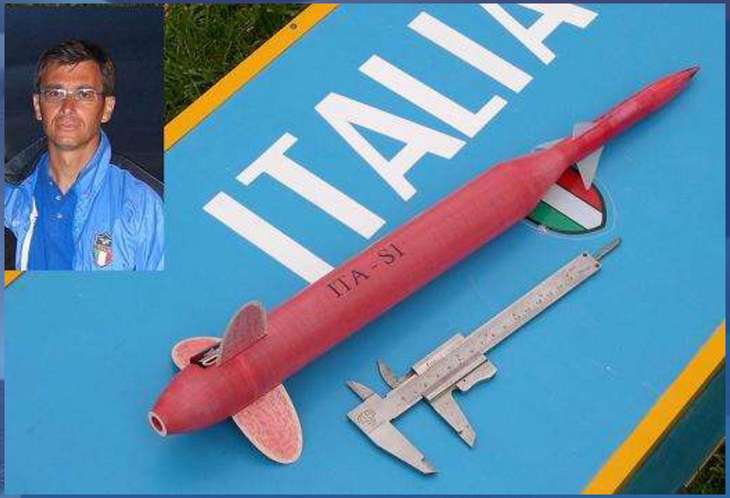
VORONOV Oleg (RUS) – 2nd
MAZZARACCHIO Antonio (ITA) – 1st
MENSHIKOV Vladimir (RUS) – 3rd

Key winning factors:

1. High-performance engines (J. Taborsky's "Delta" A2-0, A1-7), but no piston launcher.
2. Use of several numerical simulations for optimization.
3. Waiting for a launch window with excellent weather conditions.



S1B 2004 World Champion model

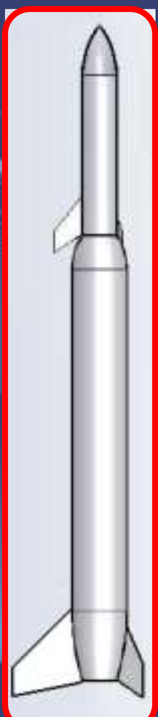


10.8. WSMC-2006. Gold medal - MENSHIKOV Vladimir (Russia)

Podium S1A (L-R):

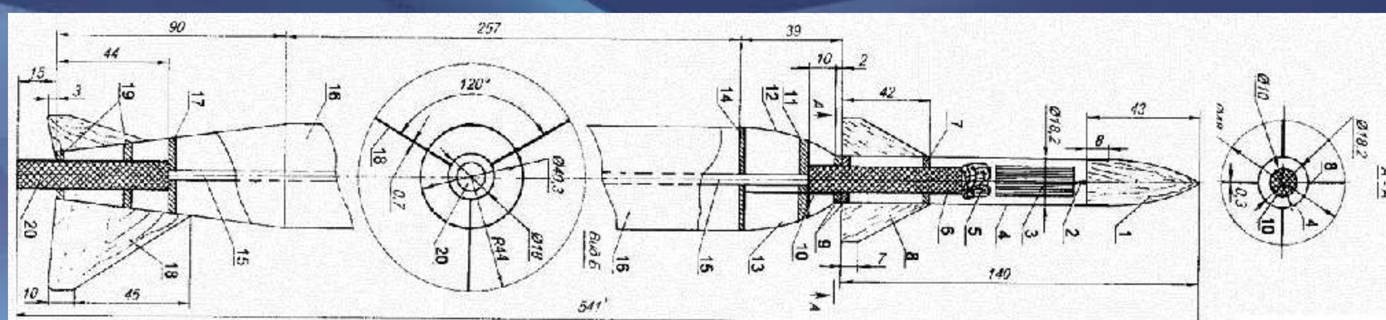
ROMANIOUK Sergei (RUS) – 2nd
MENSHIKOV Vladimir (RUS) – 1st
CUDEN Joze (SLO) – 3rd
KRCEDINAC Branislav (SCG) – 3rd

Key winning factors:



1. Very good engines:
   J. Taborsky's "Delta". 1st and 2nd stage – "compound", specific Impulse $I_{sp} \approx 1200$ N · sec / kg.

2. Intelligent model design.



3. Preparedness for competition; composure during models preparation for flights – was able to launch all 3 flights.

10.9. WSMC-2010 S1. Gold medal - CUDEN Joze (SLO)

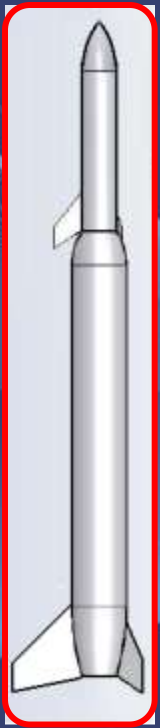
Podium S1A (L-R):

CUDEN Miha (SLO) – 2nd
CUDEN Joze (SLO) – 1st

KRASNOV Pavel (RUS) – 3rd

Key Winning factors:

1. Very good engines "Delta":
   1st and 2nd stage – "compound", specific Impulse Isp ≈ 1200 N · sec / kg.
2. Грамотный дизайн модели.



- Smooth NC-Body juncture - use a rear ejection system.
- Very smooth external surface of the 2nd stage body

10.10. WSMC-2010 S1. Gold medal - TIMOFEJEV Maksim (LTU)

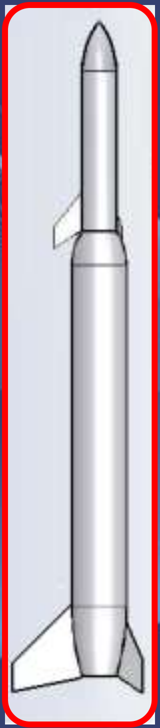
Podium S1A (L-R):
TREIKAUSKAS Mykolas (LTU) – 2nd
TIMOFEJEV Maksim (LTU) – 1st
KATANIC Zoran (SRB) – 3rd

Key Winning factors:

1. Very good engines (Piotr Sornowski's (Poland) design & fabrication):

   1st stage: PSn A8-1-1: **Specific impulse I_{sp} ≈ 1500 N · sec / kg**
   . Small delay time **t_{delay1} ≈ 0.6 sec**

   2nd stage: PSn A1-4-8: **Specific impulse I_{sp} ≈ 1200 N · sec / kg**
   Long burning time **t_{burn2} = 4 sec**
   Long delay time **t_{delay2} = 8 sec**



2. Intelligent models design

3. Perfectly vertical takeoff and flight of both stages
4. Preparedness, composure and readiness during contest
5. Commitment during pre competition prep and focus on performance specifically in S1 category

SEE NOTE

11. Modelers height vs. models flight altitudes

SEE NOTE

They are HIGH because they are TALL

Statistics of Soviet / Russian National teams:

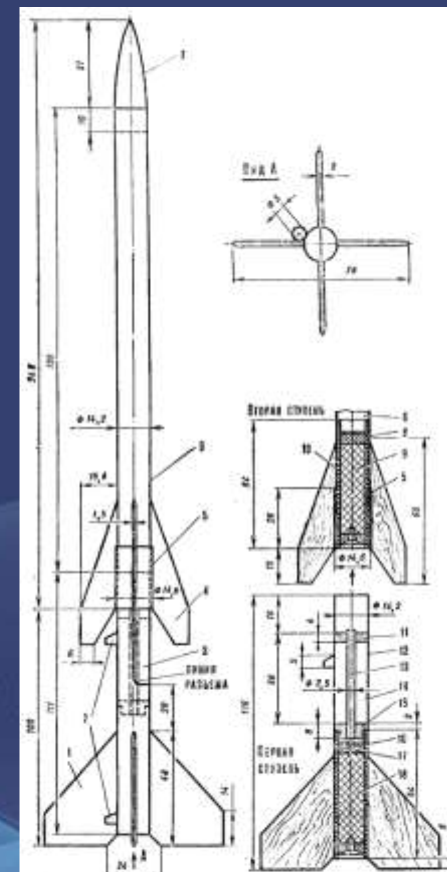
The most successful in S1 are tall (and even tallest) !

1. European Championship –1981 (Bulgaria):

S1 results:

SOLDATOV Yuri	KUZMIN Victor	MITIURIEV Alexander

4th place



The same identical models

SEE NOTE

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

2. KORIAPIN Alexey – the most successful modeler in the world (IAW WCh results in S1):

Individual medals:

A. World Championships:

- 3 (!) (WCh - 1985, 1990, 1994)

- 1 (WCh - 1996)

B. European Championships:

- 1 (EuCh - 1995)

- 1 (EuCh - 1997)

SEE NOTE

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

3. VORONOV Oleg – the most successful modeler in Europe

(IAW EuCh results in S1):

Individual medals:

A. European Championships:

 - 3 (!) (EuCh - 1995, 1997, 2005)

B. World Championships:

 - 1 (WCh - 1996)

 - 1 (WCh - 2004)

SEE NOTE

12. Conclusion

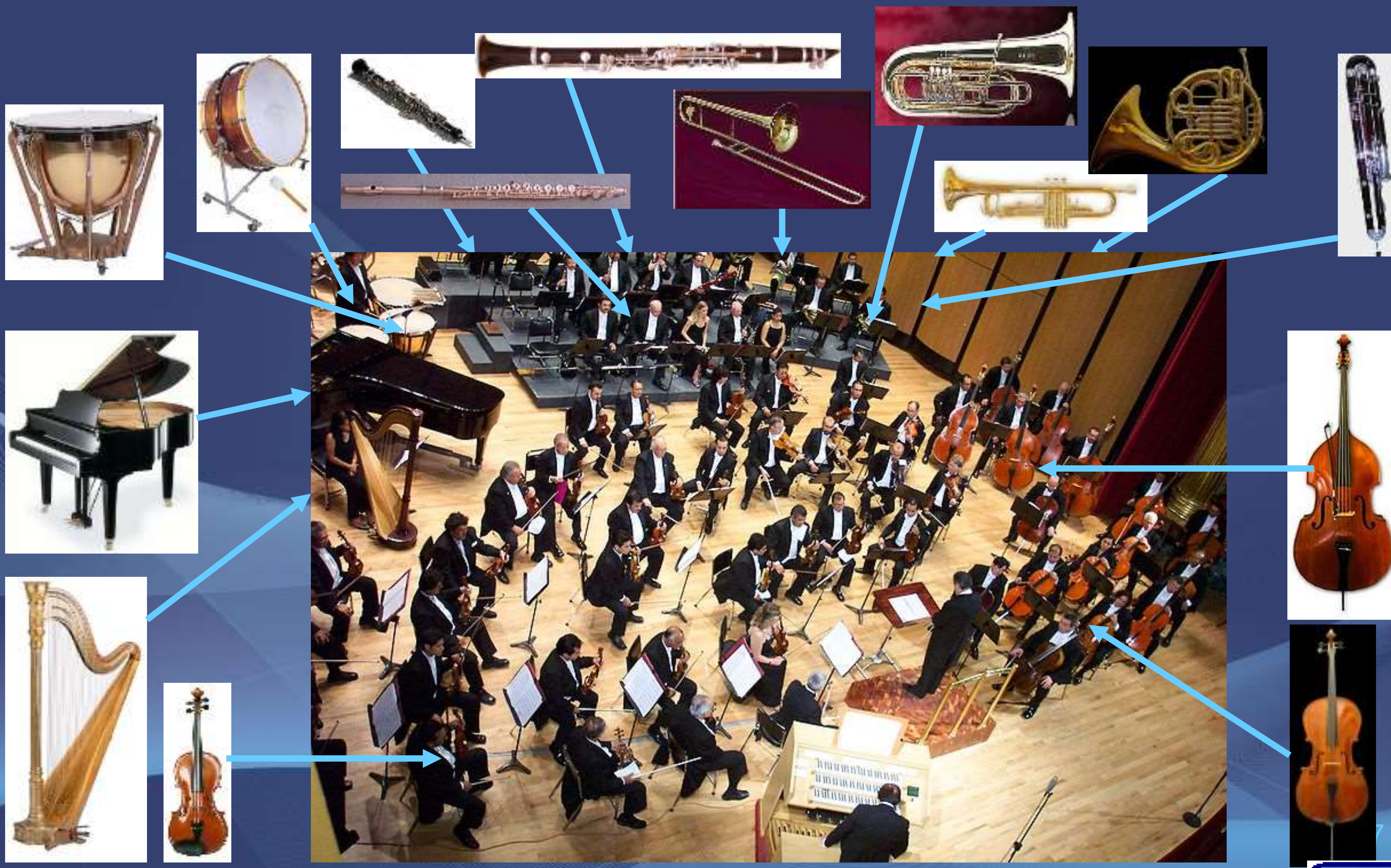
12.1. Rocket Science (Aerospace Engineering)

- INTERDISCIPLINARY integral field of science:

SEE NOTE

12.2. Rocket Science / Spacemodeling and …

Symphony Orchestra



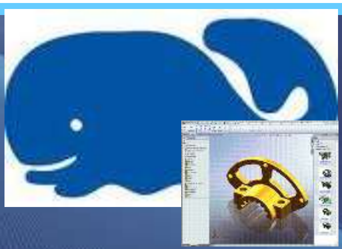
SEE NOTE

12.3. Space / Rocket modeling

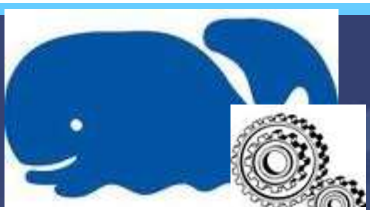
Is based on and foster of:

Understanding of physical processes (PHYSICS)

Application of mathematical tools (MATHEMATICS)



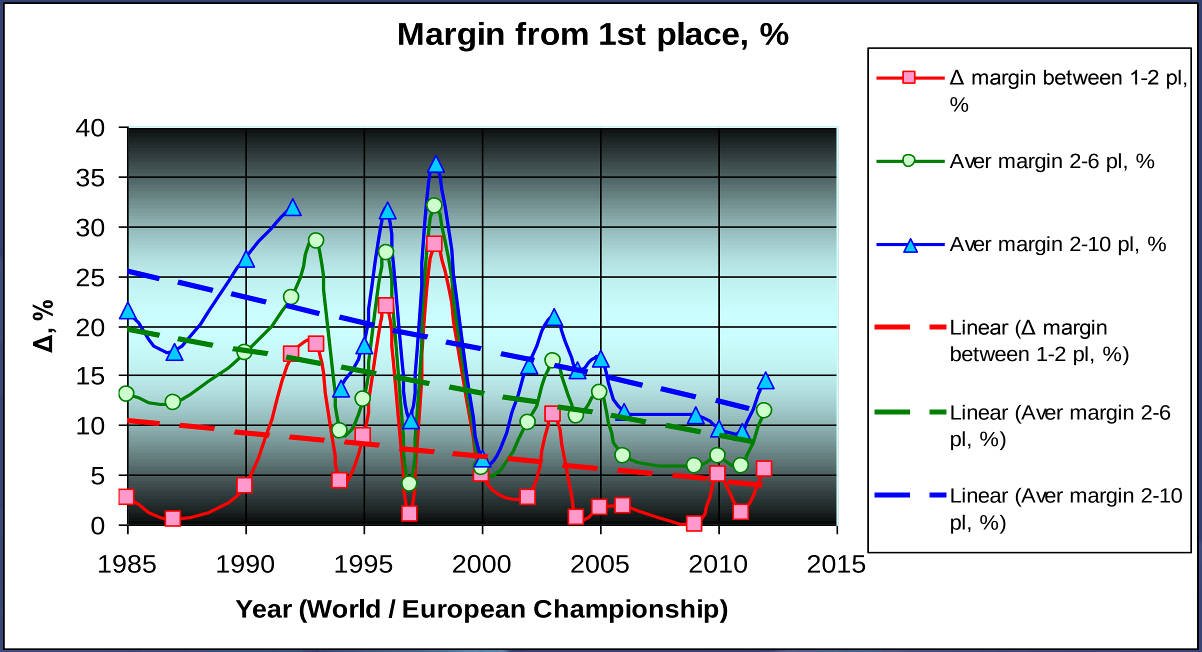
DESIGN



How to fabricate the designed (Manufacturing Techniques)

SEE NOTE

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

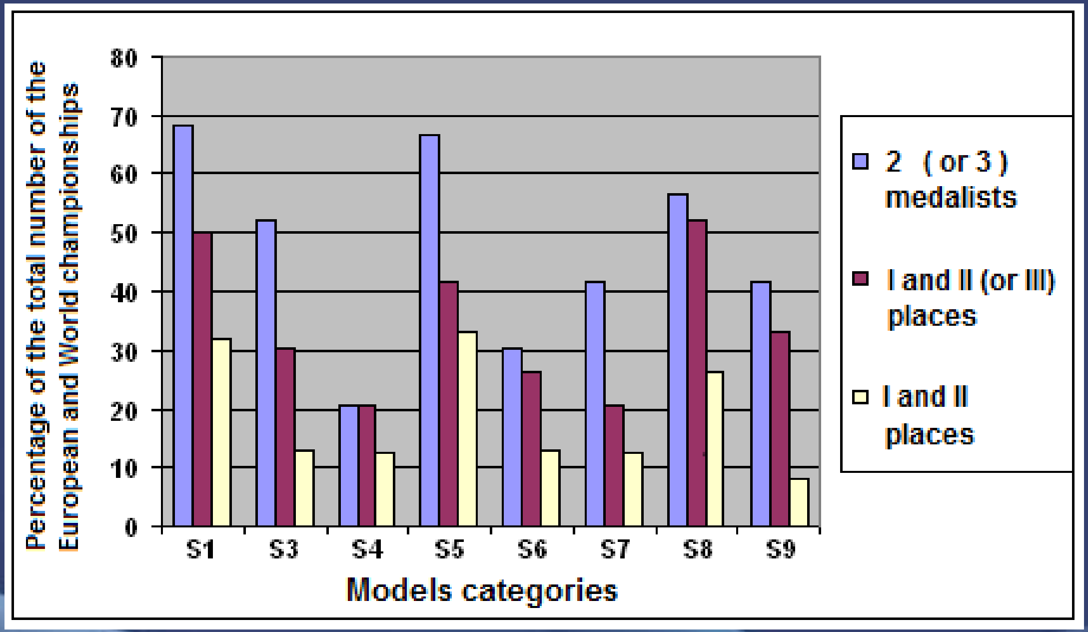


- Result margins between 1st and 2nd places have been shrinked.
- Result margins between 1st place and average results of the top 10 contenders have been shrinked also.
- During last 6 years (last 5 championships) results of the 5 top contenders were within 15% of the leader's results.

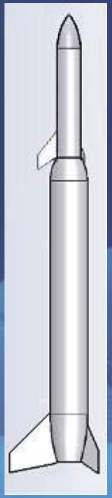
In these circumstances every, even small improvement can be decisive for a final result.
But what if you can apply everything (and plus) I said above? … <u>It is up to you!</u>

SEE NOTE

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



S 1



R&D

SEE NOTE

12.6. Your Nobleness, Sir LUCK ...

Be aggressive and make it happened!

Turn the face of Sir LUCK towards you!

SEE NOTE

12.7. Everything is in your hands

Collect as many aces, kings and trumps as you can for your hand prior the game (competition)!

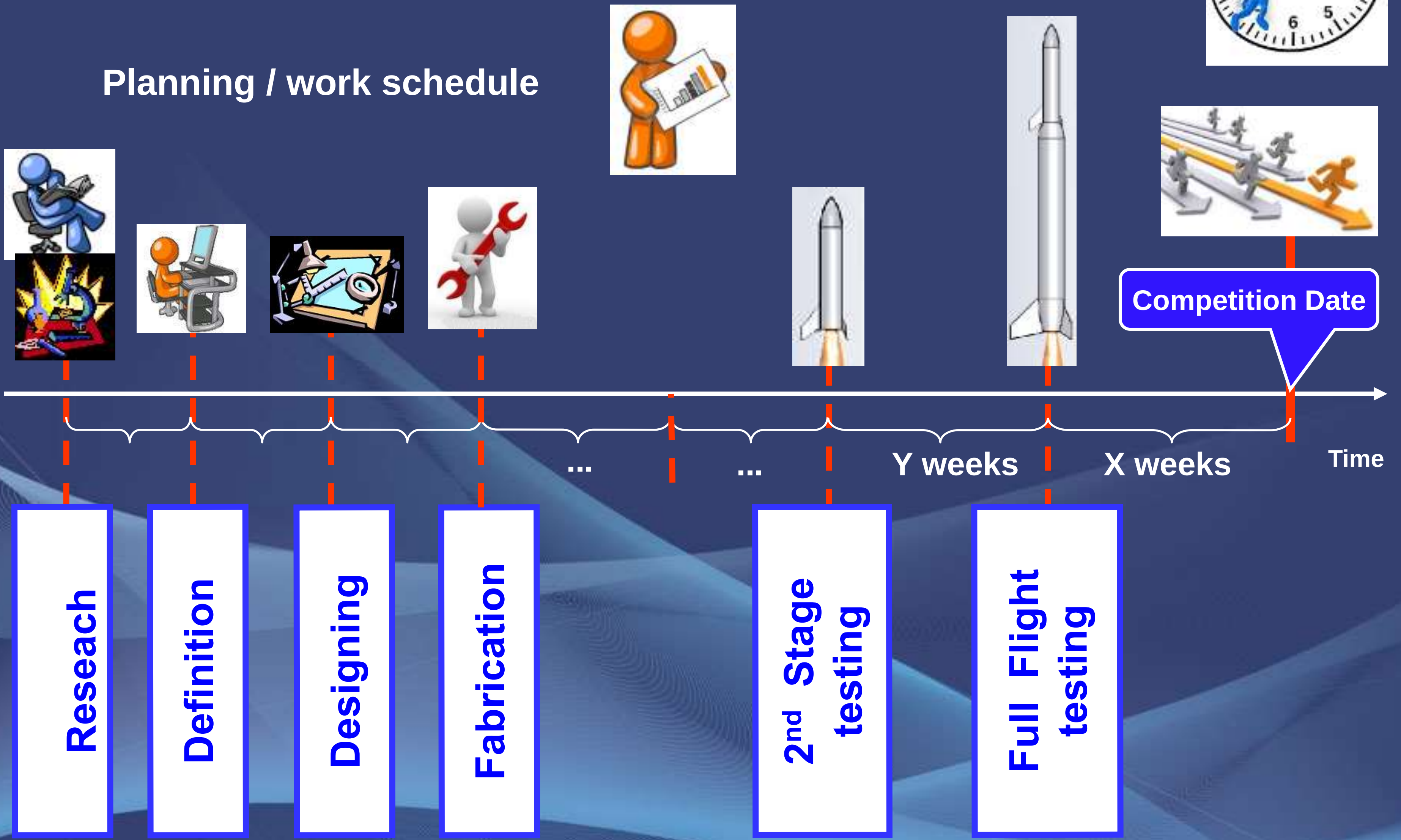
Make your own premium hand!

Don't bet in the dark!

SEE NOTE

12.8. Resources management / Time management

Planning / work schedule



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

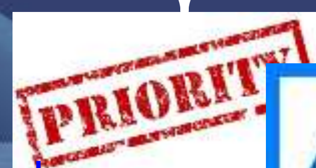
Checking of the fulfillment of a schedule

Adjustment of a schedule

SEE NOTE

12.9. Priorities

Alignment | 2nd stage drag reduction | Engines | Piston | Reliability issues | Testing (Ground Testing, Flight Testing) | … | Your own R&D

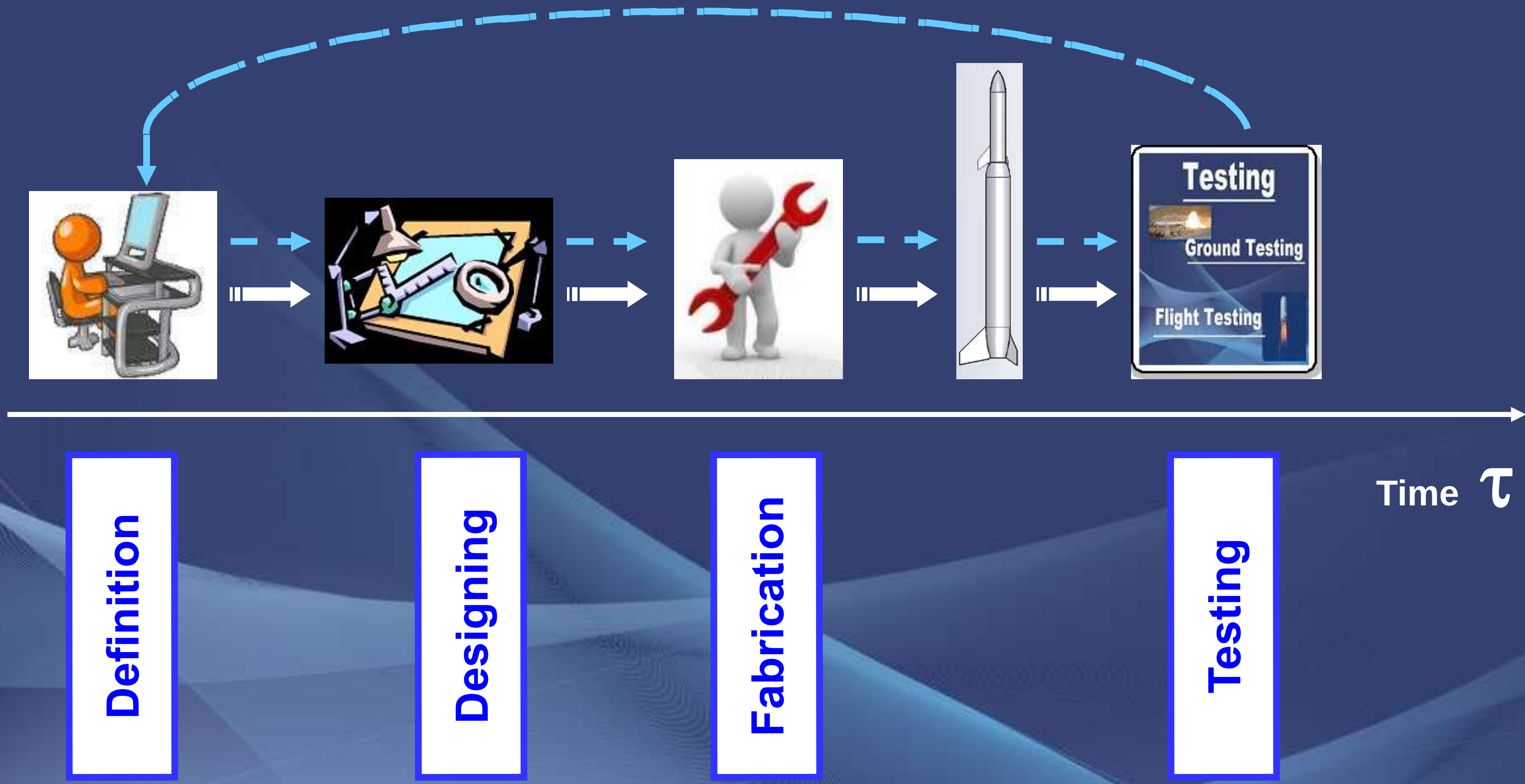


How to prioritise the topics and up to what depth to develop each direction?

TBD

SEE NOTE

12.10. Iterativeness of the New Model Process



SEE NOTE

With all these optimizations, fabrications, testing, etc. don't forget about FUN part!
Enjoy what you are doing!

Have FUN!

Enjoy open sky “million by million”!

Enjoy that flying feeling. Something like what you felt when you had launched your very first rocket!

GOOD LUCK! And GOOD SKY!

Afterward Notes

1. I hope you have found some points of interest in this presentation.

2. I would be pleased if some of the described ideas or variation of them will be applied on your future models. I would like as well (or even more) if presented material will sparks / leads to your own new ideas for performance improvement of your altitude models.

3. Some of the presented material may not be absolutely correct. Your responses / comments would be appreciated.

4. I hope the presented materials on S1 models will inspire rocketeers to make similar presentation(s) on the other FAI model categories.


the end


Questions

"What is hidden is lost. What is given becomes yours"
- Shota Rustaveli, Georgian poet

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Robert KREUTZ (USA)

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

SEE NOTE

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

SEE NOTE