Increasing the efficacy of an anti-hail rocket

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Abstract: - The paper has as research objective to increase the efficacy of an anti-hail rocket with solid propellant rocket motor (SRM). A particularity of SRM is that the rocket motor once started it cannot be stopped and restart. That induces the idea that the only control of thrust in the same conditions for pressure in burning chamber is to fragment the propellant grain in two or more parts that will split the thrust. This is possible by introducing a lag time into the pyrotechnical chain using delay devices. In this paper are presented numerical calculations for different delay time between Thrust 1 and Thrust 2 in order to obtain a maximum for the active part of the rocket trajectory inside an area of interest. This will increase the efficacity of the anti-hail rocket and as a consequence the efficiency of hail suppression activity.

Key-Words: Hail suppression activity, Anti-hail rocket, Cloud seeding, Rocket efficacy

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1 Introduction

An anti-hail rocket is a type of cloud seeding device that is fired into a cloud region where it releases a seeding agent that will prevent the formation of hail. The seeding agent is released during the rocket's flight, along a part of its trajectory. These areas where hail has great potential for formation are in general between isotherms of -6^{0}C and -10^{0}C [5], [6]. The altitude of these isotherms varies depending on location, relief characteristics, season [7], [8]. The longer the trajectory of the rocket while seeding occurs through the area between the two isotherms, the greater the efficacy of the seeding process. The seeding process begins at a certain moment of time, corresponding to a position of the trajectory and it will stop at the moment of self-destruction of the rocket (Fig.1). Important item, the time of self-destruction flows from the start of the rocket and is pyrotechnically set. This involves that the flight time is limited by the time of self-destruction, assuring a certain safety altitude when the remaining rocket body is blow-up.

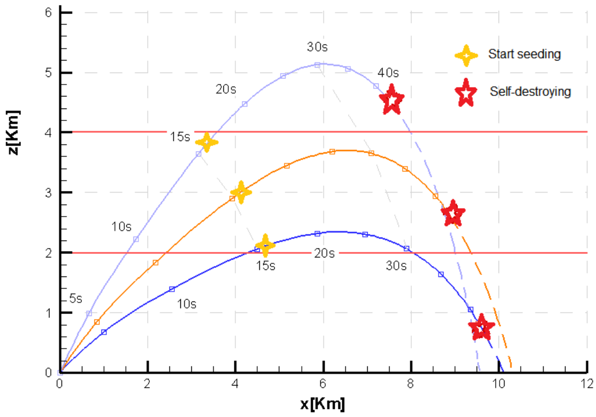

Fig. 1 Stages of operation on the trajectory

Starting from the premise of low cost, easy for exploitation and a high degree of safety in service it results that the rocket must be as simple as possible, that means an unguided rocket (avoiding all the expensive avionics component) with SRM.

A particularity of SRM is that the rocket motor once started it cannot be stopped and restart. That induces the idea that the only control of thrust in the same conditions for pressure in burning chamber is to fragment the propellant grain in two or more parts that will split the thrust. This is possible by introducing a lag (delay) time into the pyrotechnical chain using lag devices (Fig.2) [1]. The lag devices are small components that contain a pyrotechnic composition with slow rate of fire and almost no thrust for the rocket.

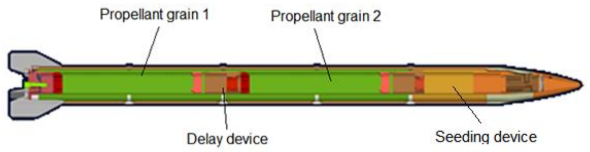

Fig. 2 Anti-hail rocket

In Romania the technology based on anti-hail rockets is implemented for more than 15 years [2]. During the time, for the beginning of the hail combat season, we observed a particularity: the altitudes of the isotherms are lower than in the mid of season.
The delay device produces a lag time that practically divides the thrust into 2 sequences (Fig.3).

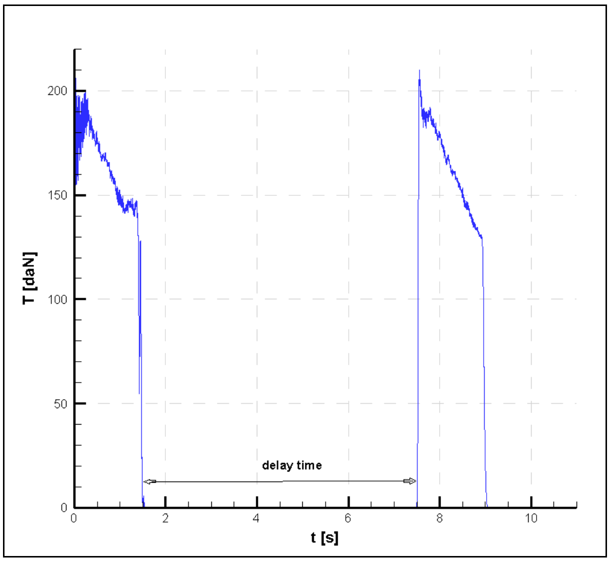

Fig. 3 Thrust diagram

The effect obtained is that the trajectory of the rocket is more flattened and elongated, which is an advantage in the case of hail combat.The scope of this paper is to analyse the lag time (delay time) between Thrust 1 and Thrust 2 in order to obtain a maximum for the active part of the rocket trajectory inside an area of interest.

2 Problem Formulation

We propose to study the influence of delay time on trajectory path of a certain anti-hail rocket [3]. First of all, there are some constrains that must be imposed to define the problem correctly:

1. The first constrain is a geometrical one and it derives from the fact that the active zone of the trajectory (the seeding zone) must be situated between the required isotherms from Table 2 with the highest probability of forming hail.
2. The second constrain is a time constrain. The seeding time t_s is very important and must be in concordance with the geometrical constrain. We will consider t_s a fix value in the problem (specific to the seeding device). The start of seeding depends on the lag time. Another condition is for the delay time which may vary from 0s to a maximum value. This maximum value for the delay time is limited by the functioning of other component devices from the pyrotechnical chain and from safety reasons. A very high delay time will allow the rocket to enter into a descendent path of the trajectory before the second propellant grain to burn. A thrust force in these conditions will accelerate the rocket to hit the ground prematurely.
3. The third constrain derives from the initial launching conditions. The launching installation (fig. 4) has predefined elevation launching angles from 5 to 5 degrees, with a minimum at 40° and a maximum at 60°. The limitations were set from safety condition: the minimum launching angle was set to prevent an impact with the ground before self-destroying event and the maximum launching angle was set to prevent a higher trajectory that can interfere with aircraft flight corridor.

Fig. 4 Launching installation

Modifying the delay time (Fig.3), we practically obtain a new thrust diagram and implicitly a new flight path. The result is that the trajectory depends on this lag time, implying a flattening of the path.

2.1 Model Description

In order to predict the trajectory of this type of unguided rocket, a six degrees of freedom (6-DOF) mathematical model is used.

According to fig. 1 we define the following geometric lengths of the trajectory:

- ✓ the active zone of the trajectory (the seeding zone) is the part of the trajectory when seeding is acting (the seeding device is functioning)
- ✓ the ideal zone of the trajectory is the part of the trajectory between the two isotherms
- ✓ the effective active zone is the part of the active zone of the trajectory between the two isotherms

The desired effect in the hail growth prevention through the technology of using rockets is higher when the effective active zone of the trajectory is longer.

2.2 Input Data

In order to perform calculations, there were established 6 cases to be studied, presented in Table1.

Table 1

	Case no.	1	2	3	4	5	6
duration [s]	t_{b1}	1.5	1.5	1.5	1.5	1.5	1.5
	delay 1	0.1	0.5	1.5	3	6	8
	t_{b2}	1.5	1.5	1.5	1.5	1.5	1.5
	delay 2	6	6	6	6	6	6
	t_s	26.7	27	26.7	26.7	26.7	27
starting moment [s]	grain 1	0	0	0	0	0	0
	device1	1.5	1.5	1.5	1.5	1.5	1.5
	grain 2	1.6	2	3	4.5	7.5	9.5
	device2	3	4	5	6	9	11
	seeding device	9.1	9.5	10.5	12	15	17
	self-destroying mechanism	35.8	36	37.2	38.7	41.7	44

It can be observed that increasing the delay time it is increased also the starting moment of the seeding device.

Besides the influence of thrust variation with time [4], the trajectory is influenced also by the different variation of rocket mass with time (fig. 5), considering a linear mass variation for each device involved in the fire chain and which involves mass consumption.

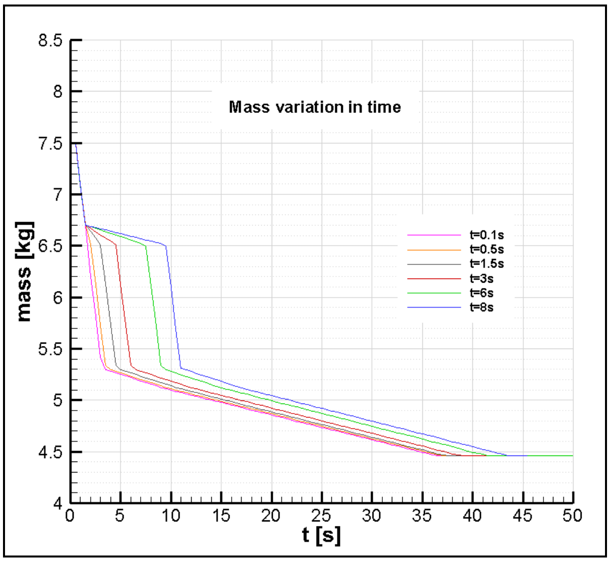

Fig. 5 Mass variation in time

Starting from the measurement of the thermal stratification of the atmosphere from Table 2 we choose as the input data the following values for minimal and maximal altitude of isotherms: H_{min}= 2500m and H_{max}= 3700m.

Table 2

Average Thermal Stratification of the Atmosphere at 12:00 in the period 15.04 -08.05.2020

No.	Date	Isotherm 0° height [m]	Isotherm -6° height [m]	Isotherm -10° height [m]
1.	15.04.2020	1115	1826	3378
2.	20.04.2020	1533	3142	3699
3.	21.04.2020	1399	2043	3765
4.	22.04.2020	1439	2128	3802
5.	23.04.2020	1677	2383	3731
6.	24.04.2020	1997	2780	3744
7.	26.04.2020	1809	2784	3709
8.	27.04.2020	1880	2758	4280
9.	06.05.2020	1652	2467	3000
10.	07.05.2020	1904	3526	3674
11.	08.05.2020	1850	3212	4143
Average		**1660**	**2640**	**3720**

Because the launching system (fig.4) is provided from the construction to allow launching angles from 5 to 5 degrees, we performed calculations starting with the launching angle of 40^0.

3 Numerical Results

We performed calculations for all the cases presented in Table 1 for different initial launching angles. The results obtained are presented in Table 3, where it was considered important to mention the following lengths of the trajectory:

- The length of seeding part of the trajectory
- The length of rocket's trajectory between the two isotherms
- The length of the seeding part of the trajectory between the two isotherms.

Table 3

Case no.	Delay time [s]	L act [m]	L ideal [m]	Lact eff. [m]	Launch Angle [^{0}]	Eff. Perf [%]	Indiv. Perf. [%]	Glob Perf [%]
1	0.1	5102	2626	2626	40^0	51.47	100.0	52.39
1	0.1	4970	4535	**4535**	45^0	91.25	100.0	90.48
1	0.1	4763	3977	2999	50^0	62.96	75.41	59.84
1	0.1	4647	3087	1365	55^0	29.37	44.22	27.23
2	0.5	5167	2628	2628	40^0	50.86	100.0	52.43
2	0.5	4978	4602	**4602**	45^0	92.45	100.0	91.82
2	0.5	4791	4017	2931	50^0	61.18	72.96	58.48
2	0.5	4565	3082	1231	55^0	26.97	39.94	24.56
3	1.5	5159	2561	2561	40^0	49.64	100.0	51.10
3	1.5	4914	4663	**4663**	45^0	94.89	100.0	93.04
3	1.5	4772	4026	2739	50^0	57.40	68.03	54.65
3	1.5	4516	3103	1070	55^0	23.69	34.48	21.35
4	3	5256	2143	2143	40^0	40.77	100.0	42.76
4	3	5023	4656	**4656**	45^0	92.69	100.0	92.90
4	3	4928	4269	2880	50^0	58.44	67.46	57.46
4	3	4762	3160	882	55^0	18.52	27.91	17.60
5	6	5432	0	0	40^0	0.00	-	0.00
5	6	5272	4300	**4212**	45^0	79.89	97.95	84.04
5	6	5127	5448	4192	50^0	81.76	76.95	83.64
5	6	4844	3364	630	55^0	13.01	18.73	12.57
5	6	4588	2935	18	60^0	0.39	0.61	0.36
6	8	5611	0	0	40^0	0.00	-	0.00
6	8	5424	3460	3460	45^0	63.79	100.0	69.03
6	8	5177	5974	**5012**	50^0	96.81	83.90	100.0
6	8	4992	3672	1046	55^0	20.95	28.49	20.87
6	8	4734	3031	0	60^0	0.00	0.00	0.00
Maximum value		*5611*	*5974*	*5012*				

The trajectories could be analyzed according to different launching angles or different delay times. In fig. 6 are presented the trajectory for case no.5 with a delay time of 6s, for different initial launching angles.

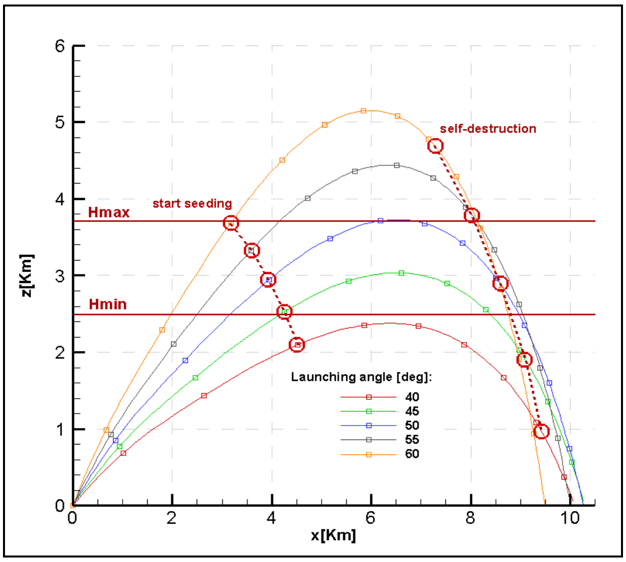

Fig.6 Trajectories for case no. 5

It can be observed that only 2 trajectories present interest for the imposed initial conditions: for 45^0 and 50^0 launching angles.

For a deeply analyses of delaying time influence we will represent the trajectories obtained for the 45 deg and 50 deg launching angle for all the 6 cases (fig.7 and fig.8).

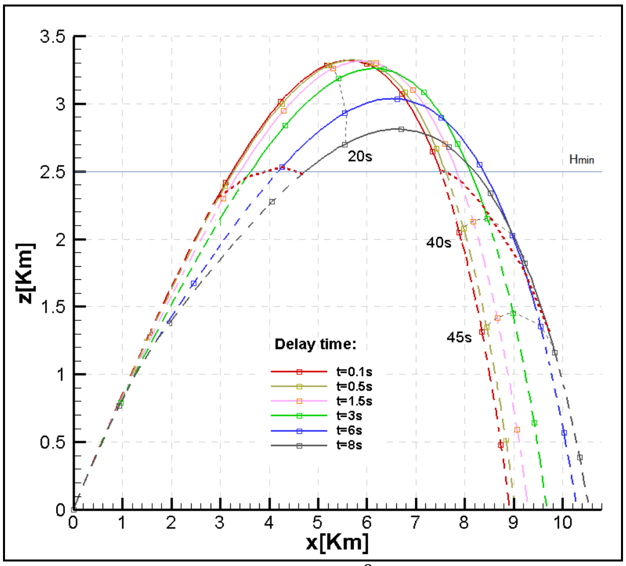

Fig. 7 Trajectories for 45^0 launching angle

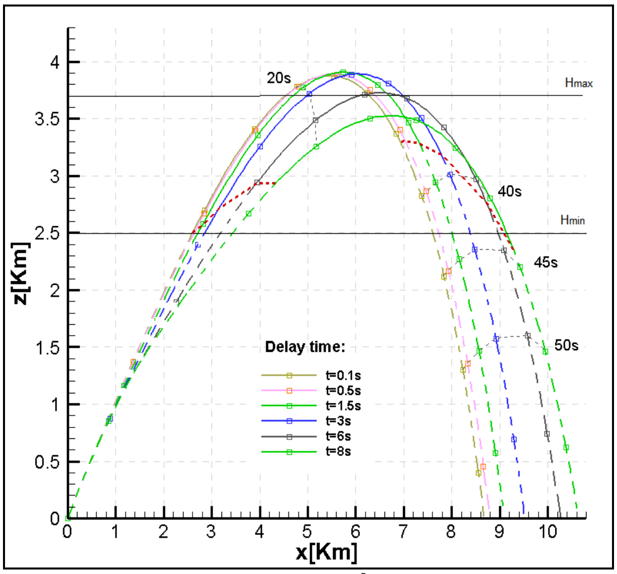

Fig. 8 Trajectories for 50^0 launching angle

In fig.7 and fig.8 it is highlighted the displacement of both the starting and ending moment of seeding. We can observe that the trajectory is longer and lower when the delay time is increased.

From fig. 9 it is obvious that the active length of the trajectory is increasing with the delay time, but as shown in fig. 10 the active trajectory between isotherms does not have the same tendency. This indicates that the limitations imposed by altitudes are an important and sensitive factor in formulating and solving the problem.

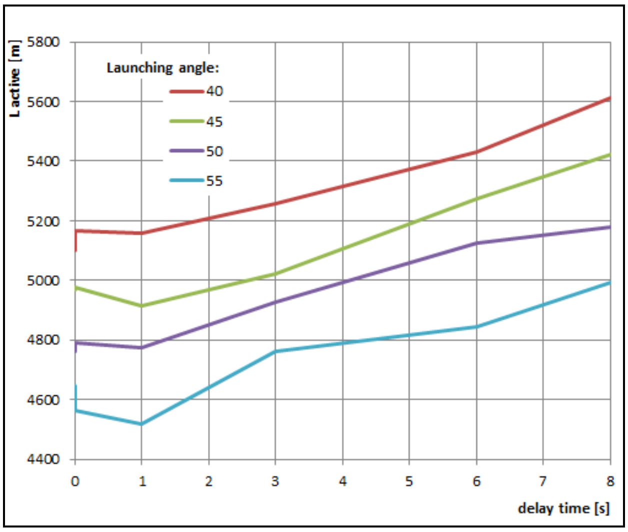

Fig.9 Active trajectory length function of delay time

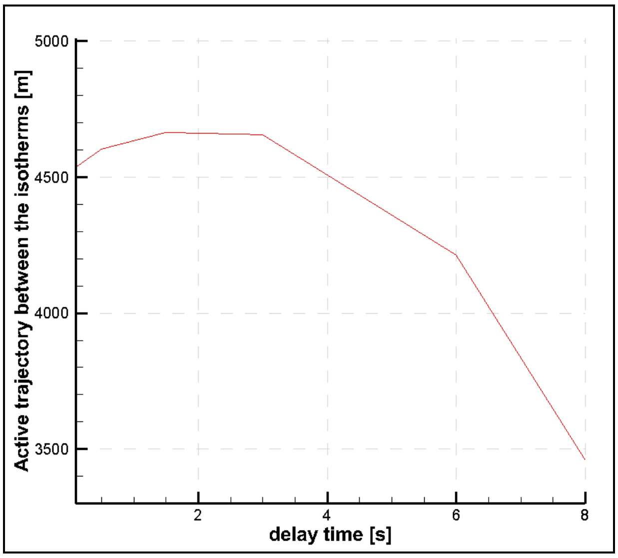

Fig.10 Active trajectory between isotherms function of delay time for 45^0 launching angle.

Analyzing fig. 10 we can observe that there is an optimal delaying time (around 2s) that maximizes the effective active trajectory between the chosen isotherms for 45^0 launching angle.

We introduced some dimensionless indicators:

- **Efficacy performance** refers to how much in percentage from the active seeding part of the trajectory satisfied the first constrain of the problem, that means it is in the area of interest between the two isotherms.
- **Individual performance** refers to how much in percentage from the rocket trajectory between the two isotherms is also an active seeding part of the trajectory.
- **Global performance** refers to the effective active seeding part of the trajectory of a particular rocket relative to the maximum calculated value of the active area. It is an indicator that will classify the cases studied relative to the best result obtained. It is also expressed in percentage.

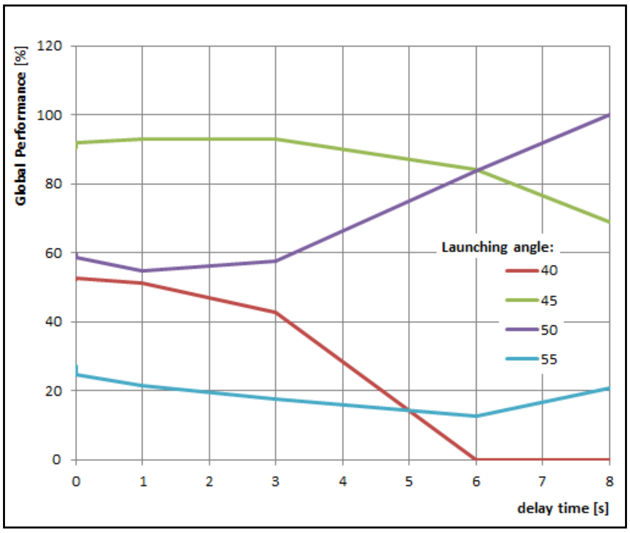

Fig.11 Global Performance dependence on delay time

We can observe from fig.11 that the global performance is higher for the trajectory of launching angle 45^0 until a certain delay time (6s) when the trajectory for 50^0 becomes more effective.

4 Conclusion

The delay time offer a useful instrument to control in a limited way the trajectory profile.

There is an optimum delaying time that ensures a maximum length for the active trajectory inside the two isotherms.

As we can see from the Table 3 the individual performance can be 100%, and still the efficacy performance could be small (40%), like for case 4 with an initial launching angle of 40^0.

Another important result is for case 6 for an initial launching angle of 50^0. In this case we obtain the longer effective active part between isotherms.

The analyze of the indicators allows to correctly set the self-destruction mechanism, and on the other hand to choose the most advantageous trajectory reported to the concrete atmosphere thermal stratification of the day.

In hail combat action a calculated number of rockets will be launched in order to cover the volume of the cloud with a high potential of hail forming. For an increase of the rocket efficacy - the efficiency of the hail combat process will be increased. A higher efficacy means to obtain similar results with a smaller number of rockets that will reduce the operation costs.

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Abbreviations

SRM - Solid propellant Rocket Motor

t_{b1} – Burning time for grain no. 1

t_{b2} – Burning time for grain no. 1

t_s – Seeding duration

L act - Active length is the length of the seeding part of the trajectory

L ideal- the ideal length is the length of rocket's trajectory between the two isotherms

Lact eff – the effective active length isthe length of the seeding part of the trajectory between the two isotherms.

Eff. Perf - Efficacy performance

Indiv. Perf - Individual performance

Glob Perf - Global performance

Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Cristina Mihailescu prepared the mathematical model, carried out the simulation and interpretation of results, contributed to problem formulation and conclusion.
Marius Radulescu provided the requirements, the input data and contributed to problem formulation, results analyses and conclusion.