SEEDING PATH AND THE SEEDING START TIME FOR THE HAIL SUPPRESSION ROCKETS

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ABSTRACT: A study has been conducted to determine the operational suitability of certain cloud seeding rockets used in Yugoslavia. Examination of the properties of hail suppression rockets used in Serbia shows that all of them have seeding paths that should be extended for about 1 km.

INTRODUCTION

The essence of the Soviet hail suppression concept, operationally applied in Yugoslavia, is rapid and massive seeding of the assumed hail embryo formation region (EFR). With some variations, depending on the type of the cloud seeded, the general goal (Bibilishvili et al., 1981) is to directly inject reagent into the layer bounded by -5°C and -15°C isotherms, preferably into the (-8°C, -12°C) layer.

In Yugoslavia, the seeding is performed by the rockets. Characteristics of the rockets used in the Socialist Republic of Serbia are summarized in the Table 1. These values are somewhat arbitrary, chosen after the performances of the Soviet models.

The purpose of this study was to check them with regard to the operational suitability. Particularly, we were interested in the seeding paths and the timing of the seeding.

Both of these values are supposed to satisfy two constraints. First, the rocket should seed on the segment of the trajectory through the targeted layer. Second, during the time available for the reagent activation, concentration of the dispersed reagent should not fall below the prescribed value of 0.1 cm^{-3}. Otherwise, the seeding path should be shortened or the total number of active nuclei released from the rocket increased.

2. BALLISTIC CONSIDERATIONS

Segments of trajectory through the designated layer are determined by the position of the target layer and the ballistic properties of the delivery vehicle.

2.1 Position of the Target Layer

Heights of the isotherms of interest vary from month to month. Because of this, all the calculations were repeated for each month of the hail suppression season, using mean monthly values of isotherm heights in the free atmosphere.

In-cloud temperatures are higher than those in the surrounding atmosphere (at least in updrafts in the lower part of the cloud). To account for this factor, we have lowered all the isotherm heights for an arbitrary value of 200 m.

The values obtained in this way are assumed to give altitudes of the in-cloud target layer above the mean sea level. Additional factor to be considered is that effective layer heights may be considerably lower, since the altitudes of launchers range up to 1400 m above the sea level. Thus, for each month of the season we have worked with a range of effective layer heights, using 200 m intervals for launching pad altitudes.

2.2 Trajectory Calculations

For all calculations we have used interpolated values from the empirical rocket trajectories, given by Jeftic (1986).

For each type of the rocket and for each possible position of the target layer, we have calculated the length of the trajectory whose top is in the middle of the layer. There were other possible choices. However, according to the seeding concept, the seeding is performed in the updraft area, and reagent released near the upper boundary of the layer would be carried outside too fast to be effective.

Table 1. Rocket Characteristics

ROCKET TYPE	TG-10	TG-5	SAKO-6	PP-6
Caliber (mm)	72	72	80	72
Length (mm)	1050	1030	1096	950
Weight (kg)	4.35	6.2	5.7	5.75
Weight of the pyrotechnic mixture (g)	400	400	400	400
Percentage of AgJ	15	15	25	20
Activity at $-10^{o}C$ (g^{-1})	$1.2x10^{12}$	$1.2x10^{12}$	$1.7x10^{12}$	$3.0x10^{12}$
Vertical range (m)	8500	5000	5200	5200
Horizontal range (m)	10000	4000	4000	4000
Elevation range (deg)	45-85	45-85	45-85	55-85
Seeding start time (s)	5-25	9-18	8-22	6-16
Seeding duration (s)	27	20	14	20
Seeding path (km)	6-7	3-3.5	2-2.5	2.5-3

The starting time for the seeding was determined as the time when the rocket reaches lower base of the layer.

Calculations were done both for ($-8^{o}C$, $-12^{o}C$) and ($-5^{o}C$, $-15^{o}C$) layers. An example is shown in the Table 2, and the resume of all the calculations in the Table 3.

The Table 3 shows that for all the rockets seeding paths should be extended for about 1 km. As for the seeding start times, they may be considered to be adequate.

It should be mentioned that empirical rocket trajectories we used for calculations were determined from the measurements in the free atmosphere. In-cloud circulations may cause deviations we did not account for. In fact, deviations from these trajectories occur even in the free atmosphere. In our opinion, however, this is a problem to be handled by the increased number of rockets used for particular seeding and not by changing the seeding path or seeding start time of the individual rocket.

3. SUFFICIENCY OF THE REAGENT CONCENTRATION

Reagent released from the rocket has a limited time to induce formation of hail embryos. This time is mainly determined by the cloud dynamics, due to the reagent being carried outside EFR. Slinn (1971) estimates this time as being around 10^2s. It is important that during this time concentrations of the dispersed reagent remain above or at least in the prescribed range of 0.1-1 cm^{-3}. Otherwise, the seeding path should be shortened.

Dispersion of the reagent is estimated after WMO (1980), by the formula

$$\sigma = \sigma_0 + C\epsilon^{1/2} t^{3/2}$$

σ is the spread parameter, σ_0 the initial spread, t time from the release and C constant (~ 0.25). ϵ is the turbulent dissipation. For organized convention it has representative values in the range of 100-500 cm^2s^{-3}. Neglecting σ_0, which has the order of a few meters, for this range of ϵ and t = 100 s, σ will range from 25 to 60 m. It appears that we may use 50 m as the representative value of the spread parameter.

If we adopt the Top Hat model of dispersion, the spread parameter may be interpreted (WMO, 1980) as the radius of the uniformly seeded cylinder. In the present context, length of this cylinder is approximately equal to the length of the seeding path.

From the Tables 1 and 3, the rocket TG-10 carries

Table 2. Seeding path and the seeding start time for the ($-8^{O}C$, $-12^{O}C$) target layer and the rocket TG-10 as a function of the launching pad altitude for the July.

Altitude (m)	Start time (s)	Seeding path (m)
0	17	3100
200	15	3300
400	13	4800
600	16	2850
800	14	3900
1000	12	4850

Table 3. Current and calculated values of seeding start time and seeding path

Rocket type		TG-10	TG-5	SAKO-6	PP-6
Current valve	Seeding start time (s)	5-25	9-18	8-22	6-16
	Seeding path (km)	6-7	3-3.5	2-2.5	2.5-3
For the (-8^{O},-12^{O}) layer	Seeding start time (s)	12-17	15-22	16-20	10-20
	Seeding path (km)	3-5	1-2	1-2	1.5-2.5
For the (-5^{O}.-15^{O}) layer	Seeding start time (s)	7-12	11-19	8-14	8-16
	Seeding path (km)	5-8	1-2.5	1.5-3.5	2-4

the smallest number of the active nuclei ($4.8x10^{14}$ at $-10^{o}C$) and requires the longest seeding path (8 km). According to the considerations described above, at the end of the time available for the reagent activation, concentration of the reagent released from this rocket will be above 7 cm^{-3}, which is more than required. This being the case, the sufficiency condition is also satisfied for the other types of the rockets.

4. CONCLUSIONS

Our analysis has shown that hail suppression rockets in the use by Serbian hail suppression system are adequate for the seeding operations as far as the seeding start time and the amount of reagent carried are concerned. For all types of the rockets, the seeding paths should be extended for about 1 km.

During this study we also noted that long-range rocket TG-10 might be uneconomical for the use on the launchers with altitude above 800 m. In these situations, TG-10 is able to seed the target layer only on the rising or descending branch of its trajectory, thus wasting much of the reagent.

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