Quick Reaction Helicopter for Safe and Efficient Hail-Suppression Operation

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ABSTRACT

Design and development of a Quick Reaction Helicopter (QRH) with its side attachments for rockets, Navigational Screen and Human Machine Interface (HMI) screen along with its safe operational norms have been presented. Side attachments have capability of carrying 2 AgI and 2 NaCl rockets on each side. Navigational screen displays the area map and also displays over it the spot location of the helicopter as per the Global Positioning Network (GPS). Yet another spot of the current location of the growing cloud is displayed on the screen map with the help of radar surveillance of cloud. This helps pilot to quickly fly towards the cloud. As the two spots coincide it indicates that pilot has reached below the cloud. QRH has to immediately land and extend its side attachments without stopping the propeller. HMI's touch screen technology guides the pilot to extend side attachments, lower the ground support, reorient the rocket holders for firing and fire them upwards by choice. Entire operation of take-off, flying, landing, firing and return to base could be completed within reaction time.

Keywords: *Hail suppression operation, Quick Reaction Helicopter, Cloud Seeding, Efficient Seeding and Reaction Time.*

1. Introduction

Hail suppression operations were attempted as early as last score of 19th century when hail cannons were fired into the cloud by 3 cm mortar albeit scientific scrutiny could not find any merit into it. Subsequently, firings of rockets of limited range were also attempted by the end of World War II but it also became futile exercise (Kumar, 2017). Till then it was believed that artificially generated heat within the cloud would melt the hailstones. This was logically invalid as in comparison to the cloud dimension and subzero temperature range in cloud the cannons' heat were negligibly small for any hailstorm. By mid-20th century the advent of cloud seeding era gave new direction to anti hail researches. By seeding a convective cloud the water content in the cloud will get condensed over several aerosols causing several droplets to grow simultaneously instead of a few. This will distribute precipitation into several small droplets (Sulakvelidge, 1969; Dennis 1977). Even if smaller droplets freeze after getting transported into subzero region(due to cloud updraft) they will melt back into innocuous liquid water during their journey from cloud to ground as most the period they will remain in above 0^0C temperature region. Based on this strategy, several methods were adopted to deliver seeding nuclei into cloud. They could be categorized as under:
(i) Ground based dispersion (ii) Base dispersion
(iii) Lateral delivery system (iv) Top-down delivery system.

Ground based dispersion suffered with severe restrictions of favorable wind and suitable cloud proximity from the point of dispersion. Base delivery system needed an aircraft to fly just below the cumulus cloud base. The approach not only suffered with severe flying hazard as the aircraft has to fly below the cloud for long period fearing of possibility of trapped under downdraft but also it is difficult to spot out the effective seeding region in a multi-cell storm. Seeding in entire region could be wasteful exercise as not all the cell might grow into hailstorm.

Lateral seeding method needs horizontal firing of rockets carrying Cloud Condensation Nuclei (CCN) or Icing Nuclei (IN) into the cloud from side. This approach not only endangers other flights in the region but also high speed of rocket permits only short interval for dispersing the seeding agents into the cloud. Further despite delivery within the cloud it may not be in the suitable temperature range for optimum result. In top-down delivery system, the pyrotechnique cartridges are carried up to the top of the cloud by aircraft and are dropped. They fall by gravity and catch fire. Fumes quickly disperse within the cloud by the in-situ updraft of cumulus cloud. This method is relatively safer and more effective than previous three but this approach also suffers with difficulty of locating the correct spot to drop the cartridges because radar reflectivity may often give diffused information at the growing stage of the multi-cell cumulus cloud.

1.1 Period of Seeding and Reaction Time

In all the methods discussed above, the seeding operation has to be performed much before the hails begin forming. This could be assessed by radar reflectivity. If the reflectivity is ≥ 45dBZ (Witt, et al 1998; Singh et al, 2011; Srivastava et al, 2011) it can be presumed that hailstones have formed in the cloud. Once hailstones have formed they will not melt back and seeding operation could be futile. This entails mandatory requirement of identifying the growing cloud at early stage before its reflectivity reaches the 45dBZ mark. This period is termed as Reaction Time. Total Reaction Time (TRT) can be defined as the time taken by any cumulus cloud with reflectivity 20dBZ to grow till it reaches 45dBZ. Kumar and Pati (2019, a&b) have given Quadratic Growth Hypotheses (QGH) for the computation of reaction time. Favorable synoptic situation, instability indices and local climatology could provide supportive information in early spotting of growing cumulus which may develop into hailstorm. If, however, the cloud is spotted at later stage (with its reflectivity >20dBZ) then the reaction time could be termed as Available Reaction Time (ART). Hence the time actually available within TRT is defined as Available Reaction Time or ART. In ten sample cases of occurrence of Hailstorm ART varied from 18 Minutes to 43 minutes for data interval of 19 minutes but if data interval is reduced to 5 minutes then ART could be up to one hour thirty minutes or more (Kumar and Pati, 2015).

1.2 Concept of efficient seeding

Concept of effective seeding was given by Vonnegut (1949). Effectiveness of seeding agent is the number of ice nuclei active at a given temperature per gram of nucleant burned. During Alberta hail project Summers et al., 1972 had noted strong temperature dependence of effective nuclei per gram of AgI burning. Number of effective nuclei at −5 °C were 8×10^{10} whereas it rapidly rose to 4×10^{15} at −20 °C. Superior performance near −5°C of acetone generators contained with AgI-NH4I solution is generally recognized in laboratory and field experiments (Dennis, 1980). Recently Kumar (2018) has presented the concept of efficient seeding which merges the concept of efficient seeding in appropriate temperature range for rapid condensation as the efficient seeding. Albeit the appropriate temperature range would vary based on the in-situ pressure and temperature structure of the atmosphere Kumar (2018) noted that for International Standard Atmosphere (ISA) this may be −3.7 °C to −19 °C.

Hence for efficient seeding, quick transportation and ingestion of seeding agents in appropriate temperature range of the in-situ atmosphere is significant in hail mitigation. This argument is also supported by ANSI/ASCE/EWRI (2015).

1.3 Basic operational necessities of safe anti hail operation

Summarizing preceding subparagraphs of this section, we can conclude the following four main necessities of any anti-hail operation:

(i) Operational Flying Hazard must be minimized.

(ii) Region of operation should be such that minimum aerospace needs to be cordoned off.

(iii) Timely delivery of seeding material within Available Reaction Time (ART).

(iv) Seeding operation should be done in appropriate temperature range so that the process of condensation could be optimized.

From any static ground based rocket launcher, one has to fire rocket in slant direction only to expand the reach of the rocket but in that case very large area has to be cordoned off for other flights, due to long rocket trajectory. Ground based vertical or near vertical firing of rocket into overhead clouds is therefore operationally viable strategy which meets all the four criteria mentioned above. However, to implement the scheme, the required categorical steps are given below:

(i) Quick Reaction Helicopter (QRH) has to be used for quickly transporting rockets carrying seeding materials below the cloud.

(ii) Two different types of Rockets must be fired. One carrying pyrotechnique cartridge for delivery in subzero region of the cloud and other one carrying powdered sodium chloride for delivery in above zero degree region of the cloud.

(iii) Satellite navigational guidance system needs to be provided to the helicopter so that pilot is able to land exactly below the growing cloud within the Available Reaction time.

(iv) Satellite controlled delivery of the pyro technique cartridge after the rocket has reached in the temperature range -5^{0}C to -15^{0}C.

(v) Satellite controlled delivery of the Sodium Chloride after the rocket has reached in the temperature range of Lifting Condensation Level.

(vi) To save time, pilot operated Human Machine Interface (HMI) system is warranted within the cockpit of helicopter so that pilot may start firing rockets immediately after landing.

(vii) Safe recovery of QRH back to Hail Control Centre.

In this paper, design and development of QRH is presented which may meet all the above mentioned characteristics of any operational anti hail mission in future.

2. Quick Reaction Helicopter (QRH) for hail Suppression Operation

External picture of such Quick Reaction Helicopter is shown in Figure 1. Cheetah helicopter (Manufactured by Hindustan Aeronautical Limited, India) is having max speed of 200 km/h and can fly very low level close to ground below the low level clouds. It has the endurance of four hours. Hence, it may meet all the requirements of suitable platform as mentioned in Section 1.3. This helicopter therefore could be fitted with following devices to convert it into appropriate QRH for any operational anti hail requirement.

(i) Navigation System screen in the cockpit.

(ii) Extension attachments for carrying the rockets.

(iii) A Human Machine Interface (HMI) screen in the cockpit.

Figure 1: Model of Cheetah helicopter fitted with rocket launcher attachments.

Figure 2: Screen installed before the pilot in the cockpit displays the area map and the spots of current location of Helicopter and that of cloud.

2.1 Navigation System screen in cockpit

One 1'x1' size screen is fitted before the pilot, which displays the geographical map of the region. Over the screen map two spots appear; one marking the location of the helicopter itself and other representing that of predicted location of cloud. Spots are digitally displayed on the screen by the

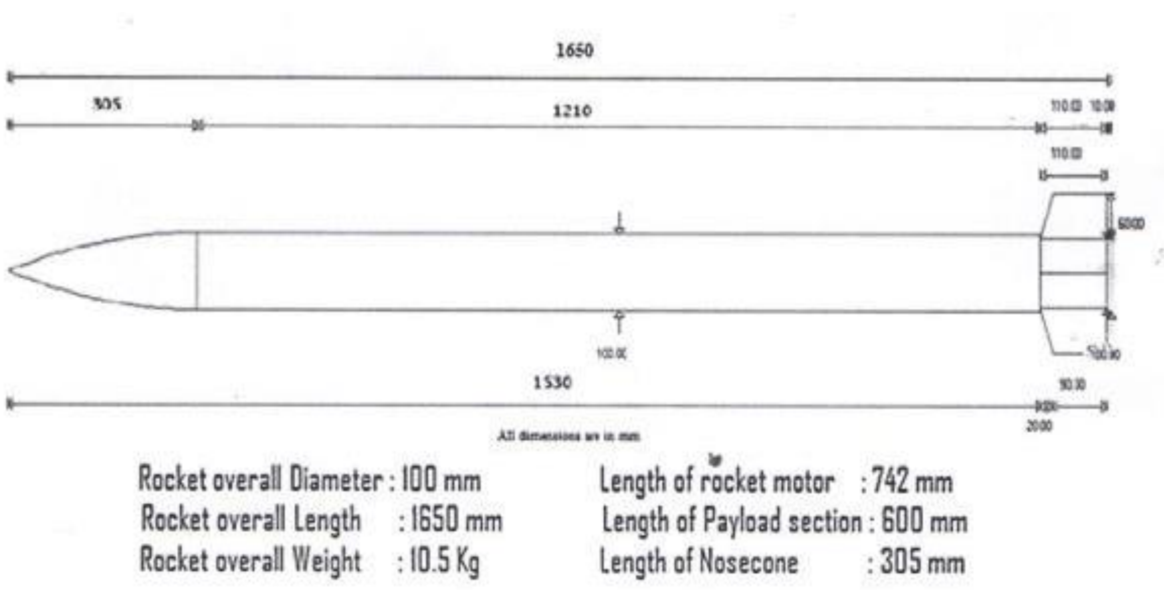


Figure 3(a): Design specification of AgI Rocket (Kumar et al. 2015).

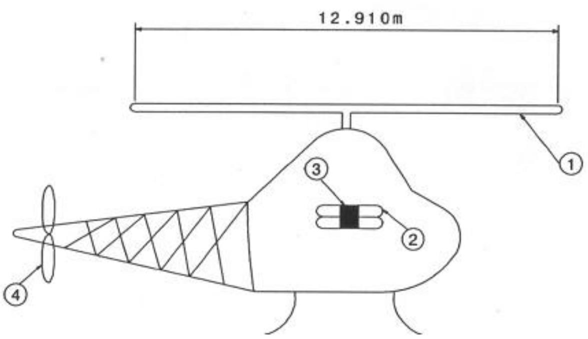
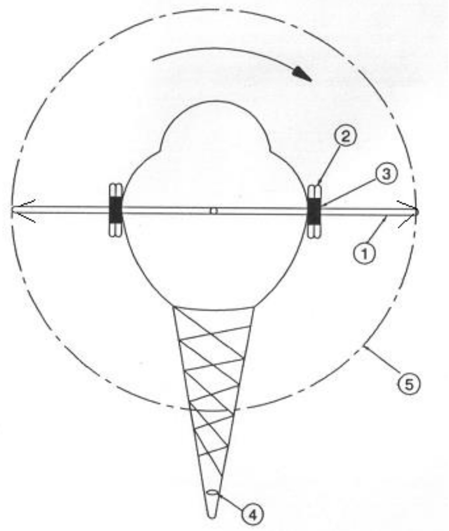
	
Side View	Top view
1 – Main Rotor diameter	
2 – Cloud Seeding Rockets	
3 – Rocket Launcher Assembly. It includes extension rods	
4 – Tail Rotor	
5 – Main Rotor periphery	

Figure 3(b): Retracted position of attachments.

Global Positioning System (GPS) link up (refer to Fig. 2). Pilot has to fly in the direction of cloud's spot. Radar also tracks the cloud continuously and pilot keeps on updating the latest position of the cloud every 3 minutes interval, as indicated by radar, from hail control hub. In case of communication failure in the helicopter, it can still fly based on the predicted value of location and land below the cloud. After flying for some time, two points tend to close-in. Once the two points coincide, it indicates that QRH is to land immediately below the potentially developing cloud. After flying for some time, the two points tend to close-in. Once the two points coincide, it indicates that QRH is to land immediately below the potentially developing cloud.

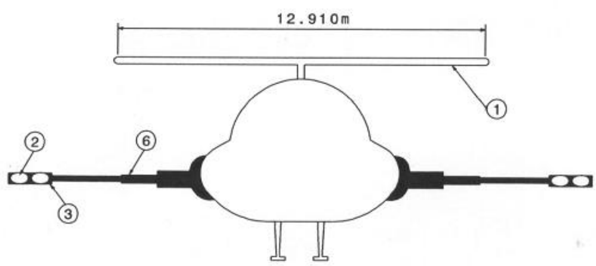
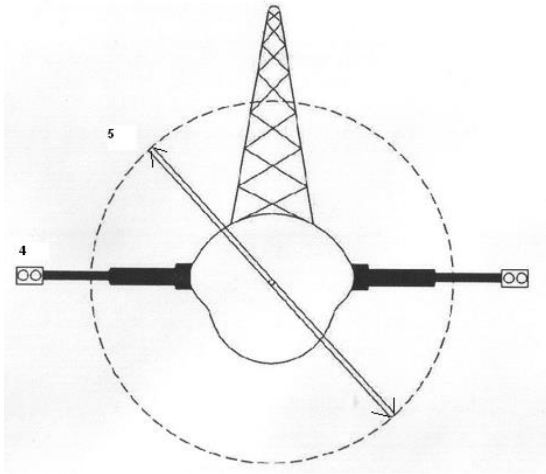
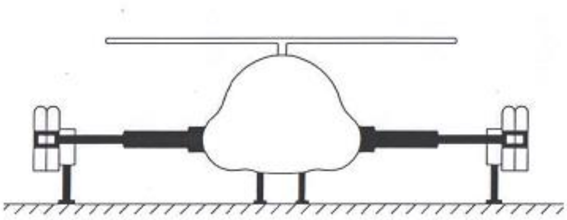
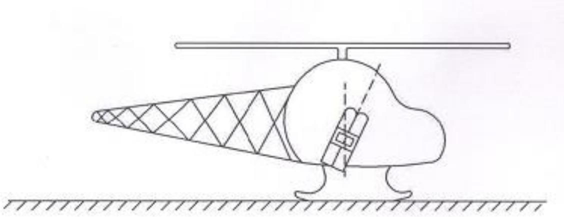
	
Front View. Rockets horizontally oriented and ground support not lowered	Top view. Rockets vertically oriented.
	
Front View. Rockets vertically oriented and ground support extended downwards up to ground level	Side View. Rockets could be reoriented up to 5^0 forward or backwards from the azimuth.
1 – Main Rotor diameter	
2 – Cloud Seeding Rockets oriented horizontally	
3 – Rocket Launcher Assembly. It includes extension rods and retracted ground support pods	
4 – Rockets in vertical firing position after reorienting vertically upward	
5 – Main Rotor periphery	
6 – Extended attachments	

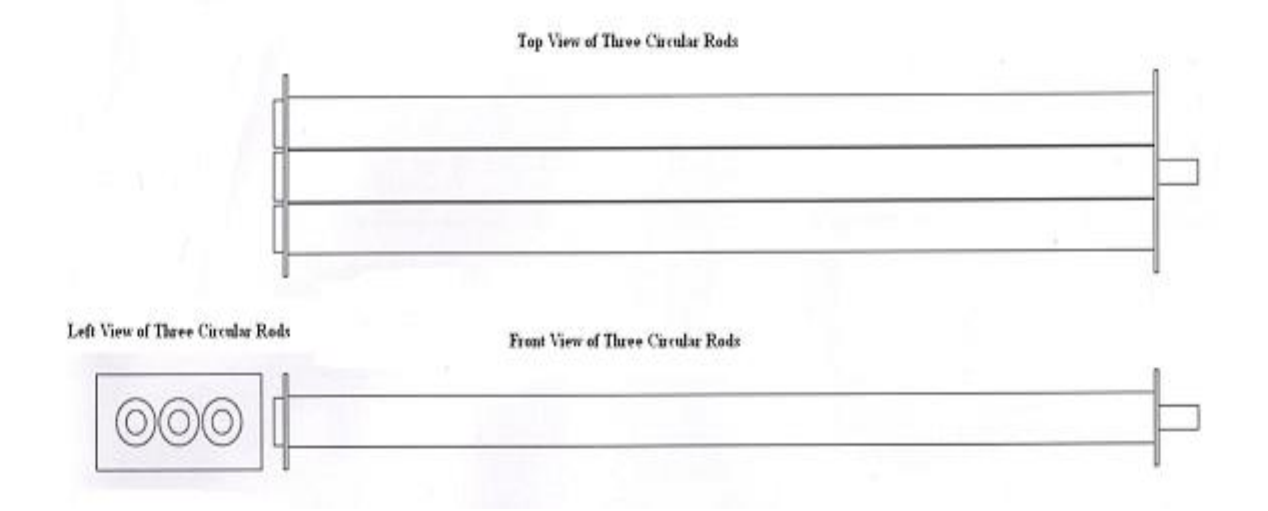
Figure 4: Extended position of attachments.

2.2 Extendable attachments for carrying the rockets

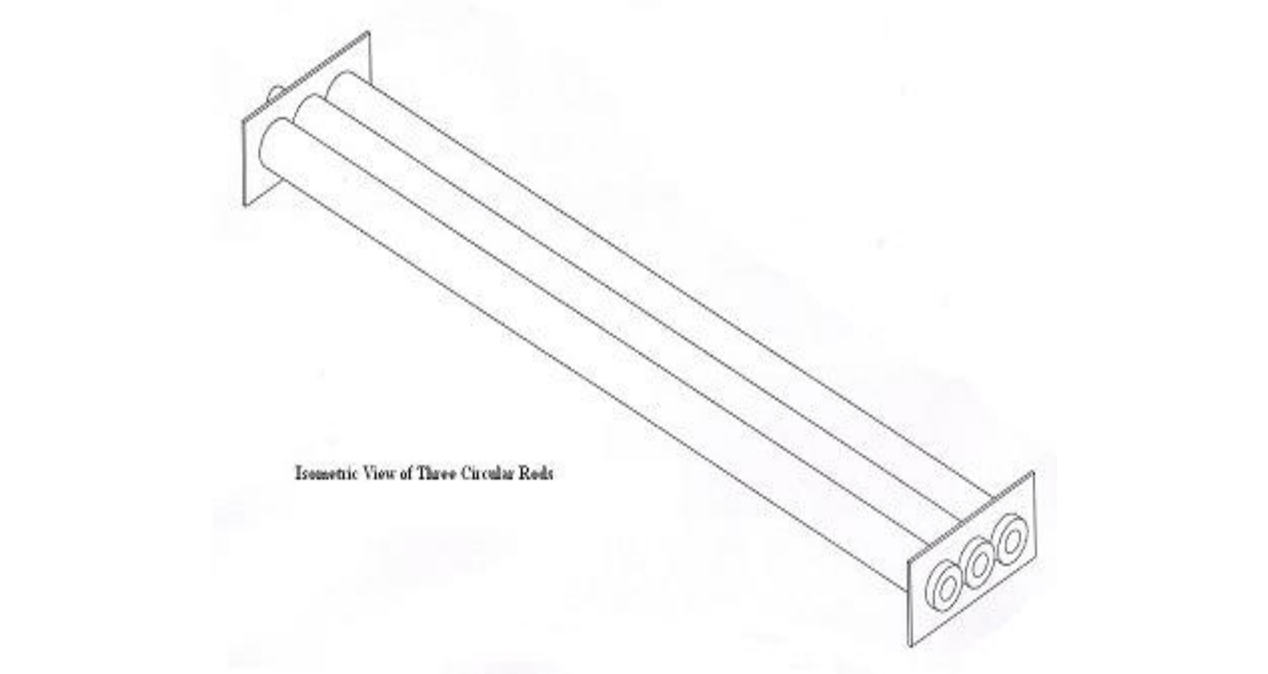
Kumar et al. (2015) have presented the design of rocket (refer Fig. 3(a)) which can be fired vertically from slots in the extendable hands of the attachments of a helicopter. Figure 3(b) shows the side view and the top view of the attachment when they are in non-extended state.

Figure 4 shows the front and the top views of the helicopter with fully extended attachments. Helicopter's side attachments initially remain in retracted position and the rockets (four on each side) are oriented horizontally. Figure 5(a)&(b) show the design details the attachment rods. There is one central rod and two side rods on either side. Central rod is attached with electric motor which draws its power from the helicopter engine. Side rods are only supportive for giving strength to the extended system. Rods' extension and retraction are based on screws. Figure 6 shows the workshop fabrication of the attachment on one side of the helicopter. White portion at the end of attachment is the holder for the four rockets. Two longer cylinders hold two longer (AgI) rockets and two smaller cylinders hold two smaller (NaCl) rockets. Figure 6(a) to (f) show sequence of actions pilot has to perform before firing the rockets into cloud.

On each side there are two NaCl rockets and two AgI rockets. Two rockets (Kumar, 2017), OLASTRA A1 for AgI pyrotechnic cartridge delivery and OLASTRA N1 for NaCl powder



5(a). Extension Rods' different views



5(b). Extension Rods isometric view

Figure 5: Attachment design.

delivery are shown in Figure 7(a)&(b) respectively. Kumar (2017) has described how payload ejection is done by Global Positioning System (GPS) based control circuit in the two types of rockets. Each NaCl carries one Kg common salt powder (≈ 5μm diameter) and each AgI rocket carries two pyrotechnic cartridges weighing a kg each. To save time while flying towards the cloud pilot has to feed into the rockets the levels of release of CCN (Cloud Condensation Nuclie) and IN (Icing Nuclie) for the NaCl and AgI rockets respectively. NaCl is released at Lifted Condensation Level (LCL) and AgI is released at -50 C level with in cloud. As Hail Control Hub (HCH) receives daily upper air data hence it is to be passed to pilot by HCH before takeoff or during flight.

2.3 A Human Machine Interface (HMI) screen in cockpit

After the pilot has reached the destination, QRH has to land on ground. HMI front window touch screen is shown in Figure 8a. After landing, entire exercise is to be performed with the help of screen installed in front of pilot which is known as Human Machine Interface (HMI). HMI helps extend its side attachments (Fig.8b) then down its ground support to hold the ground (it may be different length on two sides in uneven ground Fig.8c), orient the

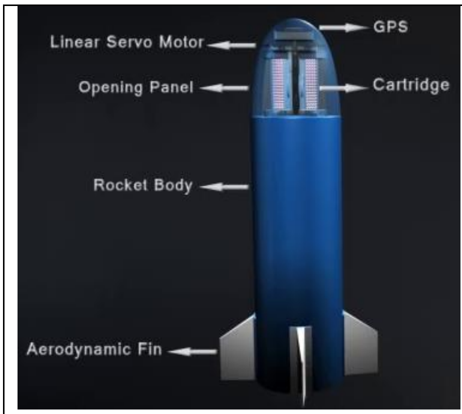
	
6(a). Attachment in retracted position.	**6 (b). Attachment in partly extended position.**
	
6(c). Attachment in fully extended position. Ground support begins to extend down.	**6(d). Ground support fully extended downwards up to ground level.**
	
6(e). Rocket holders begin to orient itself upwards.	**6(f). Rocket holder pointing upwards – tilted at desired angle from azimuth.**

Figure 6: Workshop fabrication of attachment on half size dummy model of Cheetah helicopter.

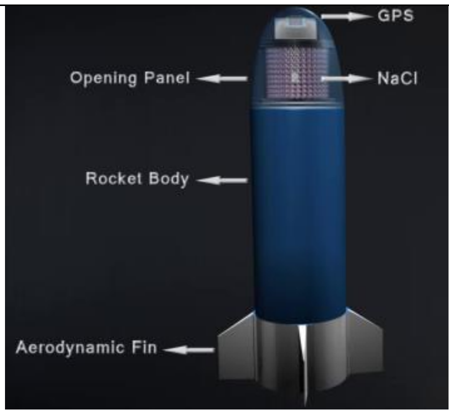
rockets upwards towards the cloud and fire them; two at a time, one each on either side (Fig.8d-f).

3. Overview of Anti Hail Operation by QRH

Schematic diagram presented in Figure 8 describes the overview of the ant hail operation. Schematic in Figure 9(a) shows that Radar of Hail Control Hub (HCH) provides information with respect to developing Hailstorm's location, speed, direction of motion and reaction time to HCH which intern would quickly disseminate the information to Air Surveillance Radar (ASR), Air Traffic Control (ATC) and to QRH Pilot. Schematic in fig 9(b) shows ASR would cordon off the Vertical Cylindrical (≈5 Km radius) Airspace for any other

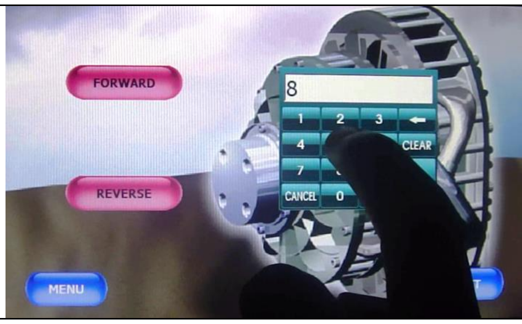


7(a). OLASTRA A1 for AgI Rocket: 165 cm length, 10 cm diameter.

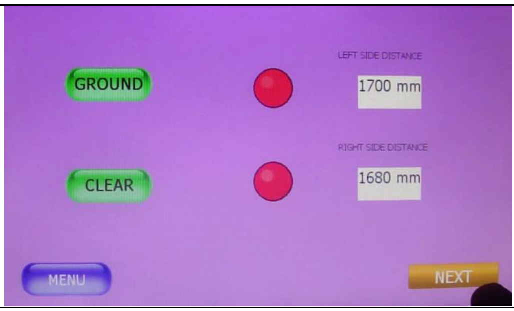


7(b). OLASTRA N1 for NaCl powder delivery: 97.5 Cm length 10 cm diameter.

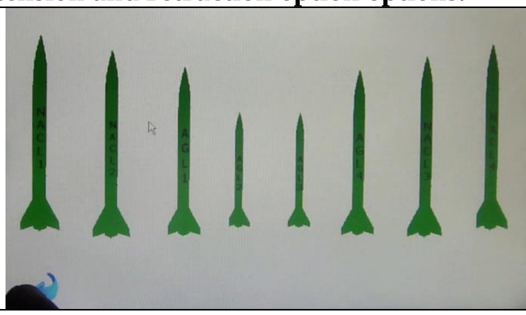
8(a). HMI front Touch Screen with four options.



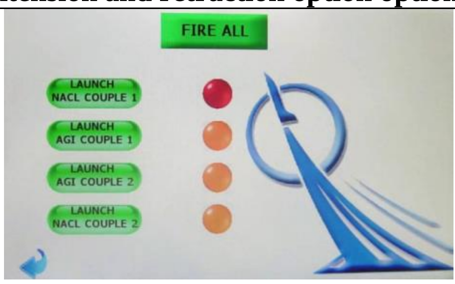
8(b). HMI Touch Screen with side attachment extension and retraction option options.



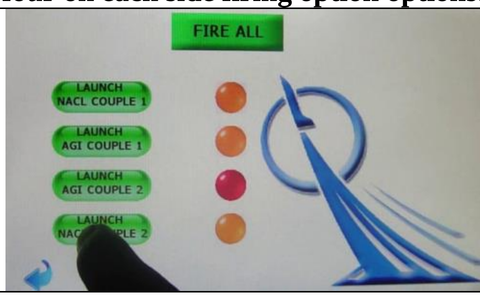
8(c). HMI Touch Screen with ground support extension and retraction option options.



8(d). HMI Touch Screen with eight rockets – four on each side firing option options.

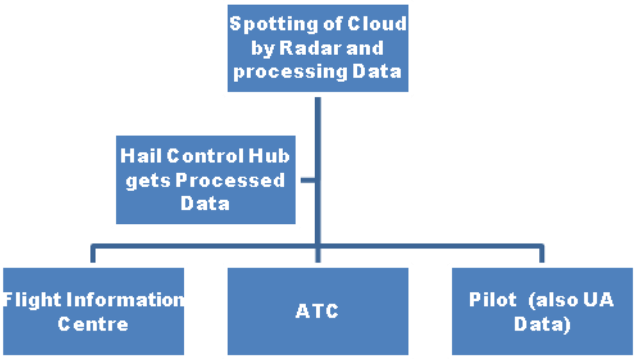


8(e). HMI Touch Screen with selectively couple firing options. Red spot shows NaCl couple rockets are selected.

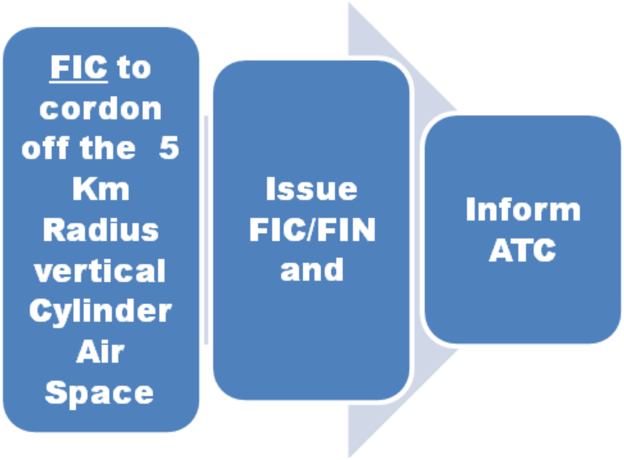


8(f). HMI Touch Screen with selectively couple firing options. Red spot shows AgI couple rockets are selected.

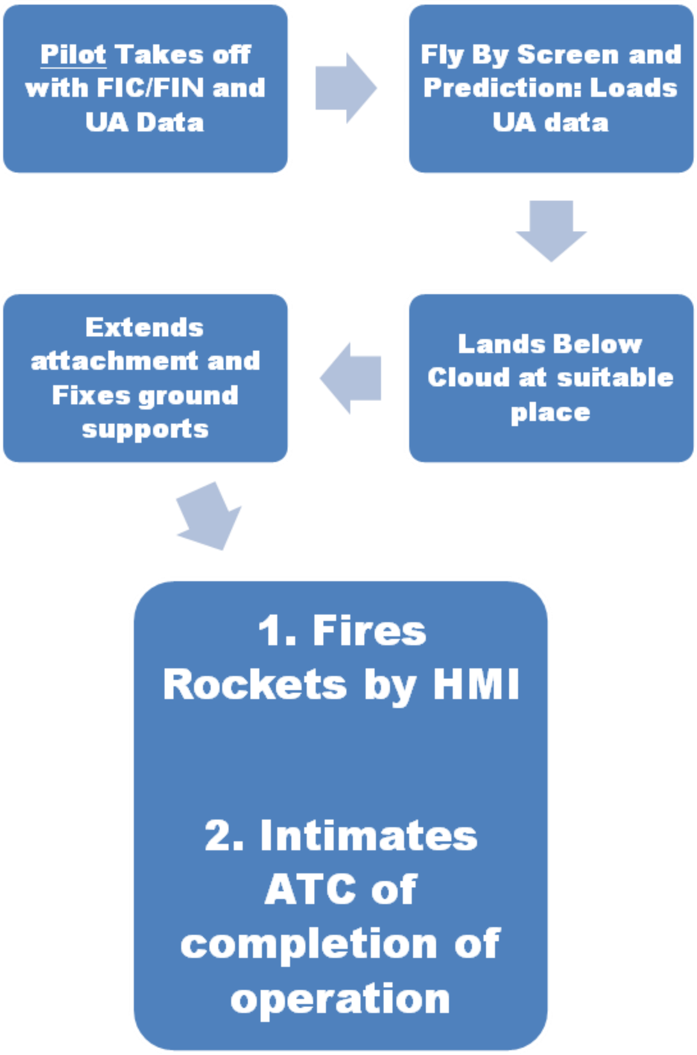
Figure 8: Human Machine interface (HMI) Screen Installed in front of the Pilot in Cockpit.


Spotting of Cloud by Radar and processing Data
Hail Control Hub gets Processed Data
Flight Information Centre
ATC
Pilot (also UA Data)

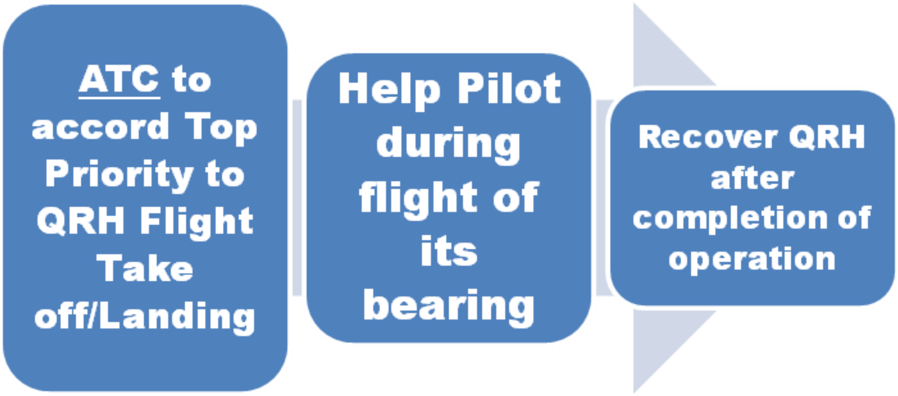
9 (a)


FIC to cordon off the 5 Km Radius vertical Cylinder Air Space
Issue FIC/FIN and
Inform ATC

9 (b)


Pilot Takes off with FIC/FIN and UA Data
Fly By Screen and Prediction: Loads UA data
Lands Below Cloud at suitable place
Extends attachment and Fixes ground supports
1. Fires Rockets by HMI
2. Intimates ATC of completion of operation

9 (c)



9 (d)

Figure 9: Schematic of Anti Hail Operation with the help of Quick reaction Helicopter.

flights and also issue the Flight Information Centre/Flight Information Number (FIC/FIN) to pilot on priority. Schematic in fig 9(c) shows Pilot takes off with upper air (UA) temperature data. While flying towards the hail cloud by GNSS guided navigation screen pilot also feeds the level of release of seeding material for the AgI and NaCl rockets. QRH lands below the cloud at suitable place and attachments are extended, ground support is lowered and rockets are oriented towards near vertical direction and fired. Thereafter pilot returns back to base. Schematic in fig 9(d) shows ATC would permit flying of QRH to its destination on top priority and would also recover the QRH on top priority after the QRH scoots away and returns to base after completing the mission.

4. Flying Hazards and Evasive Methods

Byers and Braham (1948) theory of down draft states that falling raindrop initiates it. But it is against the observed facts as many Indian southwest monsoon cumulus clouds are often observed to precipitate without any downdraft. Congelation theory of downdraft (Mull and Rao-1950) suggest some presence of ice crystals or small grapples as the prerequisite for the initiation of downdraft. Snow, crystals, grapples or hail melt while below the 0^0C level and cause cooling. This causes negative buoyancy and downdraft is initiated. The air is thus cooled and starts descending. Falling droplets' negative buoyancy is further accelerated due to part evaporation. Presence of ice crystals or grapples would need high reflectivity say ≈40 dBz or so. Hence if the helicopter is flying much before the 45dBZ reflectivity it has low chances (albeit not nil chances) of getting trapped in downdraft. If by any chance pilot observes that downdraft has begun, then it is advisable to abandon the mission and return to the base, skirting round the cloud mass. Cheetah helicopter has that versatility of quick change of path with least degree of turn. Hence, for any "Hail Suppression Mission" the best utilization of Total Reaction Time has to be made. Total reaction time is the time period between growths of reflectivity from 20 dBz to 45 dBZ.

5. Conclusions

(i) Design and development of Quick Reaction Helicopter (QRH) has been presented.

(ii) Before takeoff, pilot is provided with Total Reaction Time (TRT) as computed by the Pre Hail detection Algorithm. So that the task has got to be completed within that time frame. TRT is the time taken by growing cumulus to grow from its reflectivity of 20 dBZ till it becomes 45 dBZ.

(iii) To speed up the process, cockpit is fitted with Global Positioning Network (GPS) supported Navigational Screen which displays the area map and overlay two positional spots – one that of QRH and other of growing cloud.

(iv) After landing below the cloud, the Human Machine Interface (HMI) screen fitted in the cockpit helps pilot to quickly perform all the operations needed before, during and after firing of rockets just by touch screen technology. After completion of mission, pilot can safely return to base if operations are completed within the reaction time.

(v) Safe operational norms in anti hail operation through Quick Reaction Helicopter has been described.

Acknowledgements

The author is deeply grateful to National Initiative on Climate Resilient Agriculture (NICRA), Indian Council of Agricultural Research (ICAR) for funding the project entitled "Hailstorm Management Strategy in Agriculture" based on which this paper has been written. He is also thankful to MIT College of Engineering, Pune for providing all the possible help in successful completion of the project. This work has been enlisted in the Indian Patents Register under Indian Patents Act by ICAR vide Application No. 1324/MUM/2012, Journal 21/2014 dated 23 May 2014.

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