SARRIM: A TOOL TO FOLLOW THE ROCKET RELEASES FOR THE CNES ENVIRONEMENT AND SAFETY DIVISION ON THE EUROPEAN SPACEPORT OF KOUROU (FRENCH GUYANA)

Marco Cencetti[1], Vince Veilleur[1], Armand Albergel[2] and Christophe Olry[2]
[1] CNES, Service Environnement et Sauvegarde Sol, BP 726 97387 Kourou cedex – France
2 ARIA Technologies – 8-10, rue de la Ferme – 92 100 Boulogne-Billancourt – France

INTRODUCTION

The environment and particularly the air quality supervision is a constant preoccupation to the Safety and Environment Division of the CNES (French Space Agency) in Kourou, French Guyana. Since 1992, CNES and ARIA Technologies have developed conjointly atmospheric dispersion models for predicting the behaviour of rocket exhausts in the troposphere. These models are routinely used to assess the environmental impact of exhaust products from rocket engines with respect to air quality standards, toxicity thresholds and potential bio-ecological effects. The concept of a PC, easy and quick application, was initiated very early for all ARIANE 4 and ARIANE 5 launches from the Kourou Spaceport. In this program, the Safety and Environment Division of the CNES has in charge in supplying predictions and in organizing a monitoring program for every launch.

The idea prevailing during the tool development was to have and use a same tool for:

(1) Mission planning activities and environmental assessment ;
(2) Pre-launch forecasts of the environmental effects of launch operation and ultimate decision concerning the localisation of the monitoring environment network and the management of the public observation sites;
(3) Post-launch environmental analysis (verifying accuracy of the model, providing a database which could be used in making model improvements).

SARRIM (as Stratified Atmosphere Rocket Release Impact Model) Software was developed as a “multi function” atmospheric dispersion model dealing with:

- Solid and liquid propellant rocket releases ;
- Nominal launch ;
- Launch failure (fire ball and scattered solid propellant) ;
- Controlled propellant fires ;
- Booster test bench ;

SARRIM can be used both for operational and impact assessment purposes. Using the last radio sounding done at one hour before the launch must give pertinent info in the few minutes after receiving the radiosounding data. At the other hand, using a database of more than 15 years of in-situ radiosoundings, SARRIM can easily screen the database to identify the worst case for mission planning and environmental assessment reports. SARRIM was design first for the ARIANE 5 program impact assessment (Albergel, 1992) and has been regularly improved introducing short range assessment, liquid propellant rockets (Traissac, 1998) and acid fallouts.

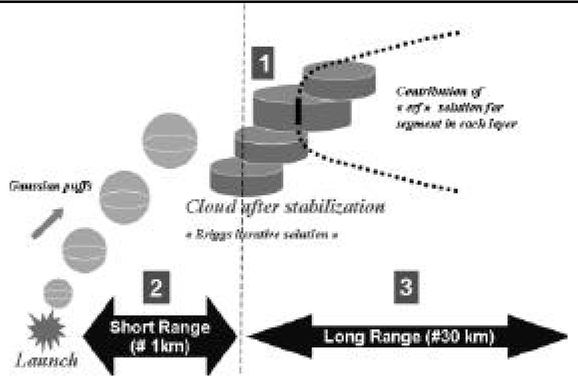
MODEL BRIEF DESCRIPTION

The burning of rocket engines during the first few seconds immediately before and after vehicle launches gives a large cloud of hot and buoyant exhaust products near the ground level. The cloud rise and entrains ambient air until the cloud reaches an approximate equilibrium with ambient conditions (temperature, density, speed, and turbulence). The cloud is then called the “stabilized cloud”. Considering the emission time very short comparing with the travel time in the atmosphere, we’ll also do the assumption of instantaneous releases. The

general algorithm is designed to get an instantaneous answer on simple PC. The shape, the content and the localization of the "stabilized" cloud are computed first.
This "stabilized" cloud allowed to compute (**Figure 1**):

- Short range impact using a multi-puffs description (the initial release is divided in several puffs) knowing the initial condition (as flame trench orientation), and the final conditions (described by the cloud after stabilization) ;
- Long range impact computed as the contribution of vertical segment sources each segment corresponding to a layer as defined in the radiosounding.

So, the "stabilized" cloud (Briggs 1969) plays here a key rule because short and long distances are highly dependant of this first computation.



Step 1 : Computation of the cloud after stabilization (Figure 3)
Step 2 : Computation of gas (HCl, CO, NOx) and alumina (Al_2O_3) particles concentration, doses and deposition for short range distances using a puff model based on the initial jet condition and the final cloud after stabilization (Figure 4)
Step 3 : Computation of gas (HCl, CO, NOx) and alumina (Al_2O_3) particles concentration, doses and deposition for long range distances using the sum of "Erf" function (Figure 5)

Figure 1 : Algorithm is strongly dependant on the computation of the "stabilized" cloud

To deliver a light volume of pertinent results, SARRIM will compute for gas and particles, directly the arrival/departure time, the peak, 10mn average doses and total deposition (see Figure 2). Spatial maximum and maps of these parameters are the main output of the models.

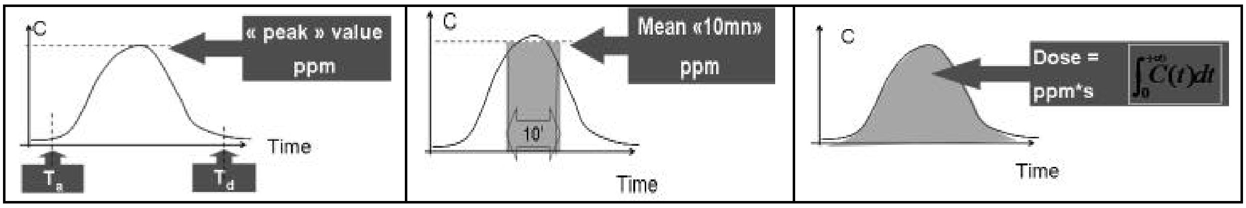


Figure 2 : Main results at receptor points: arrival/departure times, peak values, 10mn average doses and total deposition

For model output, we are using an enhanced graphic package that allowed visualizing easily all main results of the computation.

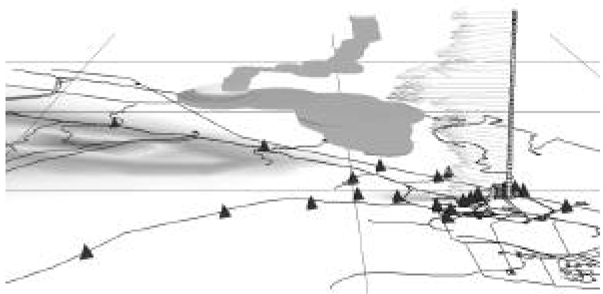


Figure 3 : 3D data and result visualisation: Arrows represent the radiosounding winds, the cloud just after stabilisation, main receptors (monitoring points), long range HCl impact for an Ariane5 launch (A502)

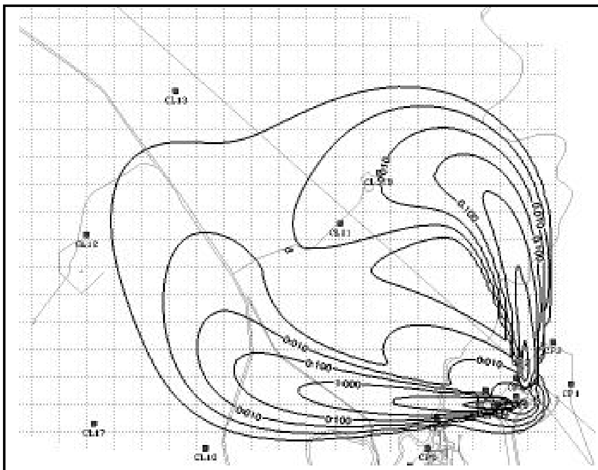


Figure 4 : Short range HCl impact near the pad. The two flame trenches give (ppm

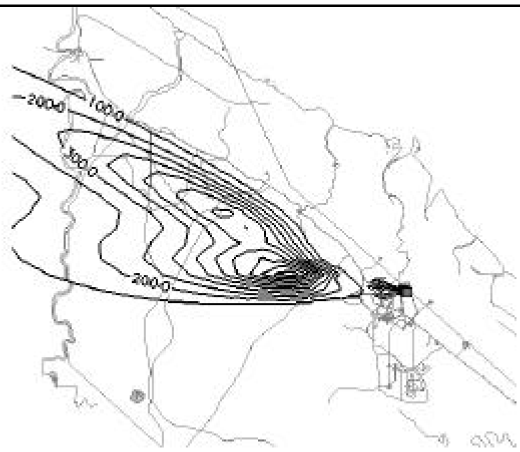


Figure 5 : Long range Al_2O_3 deposition 25 km from the pad (mg/m^2)

CHARACTERIZATION OF THE FALLOUT

Some field experiments (as tests of boosters on benches) have shown acid fallout explained as water droplet formation and growth around Al_2O_3 particles and HCl dissolved inside the droplet water. Considering previous studies done by the NASA and by the CNES (Démol, 1997), we have implemented a complementary module that can describe the particles arriving at the ground level: its diameter, the fraction solid vs liquid, and pH.

Initial conditions

SARRIM considers 9 classes of initial particles 150, 200, 300, 400, 500, 750, 1000, 1250 and 2000 with 30% of liquid and 70% of solid. The configuration is here one spherical Al_2O_3 nuclide, of course direct observations show several solid nuclei inside the same droplet.

Direct Condensation/ Evaporation process

This process is a direct description of increasing or decreasing the droplet diameters by condensation or vaporisation of water around one droplet. Considering that the heat diffusion is instantaneous:

$$r\frac{dr}{dt} = \frac{s-1}{F_k + F_d} \qquad F_k = \frac{L_v^2 \times \rho_l}{K \times Rv \times T^2} \text{ and } F_d = \frac{Rn \times T \times \rho_l}{es_\infty(T) \times D}$$

with :

s : Ambient relative humidity

L_v : Specific condensation heat ($J.kg^{-1}$)

ρ_l : water specific mass ($kg.m^{-3}$)

$es_\infty(T)$: vapour pressure at saturation (free air/water interface (Pa))

K: Air thermal conductivity ($Wm^{-1}K^{-1}$)

T : temperature (K)

D : diffusivity of vapour in air ($m^2.s^{-1}$)

R_v: Ideal gas constant ($J.kg^{-1}.K^{-1}$

This mechanism of producing acid fallout is very important mostly in Guyana where the lower layer of the atmosphere is often near saturation. The direct condensation/ evaporation process can not alone explain the largest droplets that we can find.

Coalescence process

This process describes the transformation of two droplets in one when they collide with each other. Of course there is an efficiency coefficient, since every collision does not create a new droplet

$$\frac{dR}{dz} = \frac{p}{3} \int_{r_{\min}}^{R} E_{coll}(R,r) \times r^3 \times \left(1 + \frac{r}{R}\right)^2 \times \left(1 - \frac{u(r)}{u(R)}\right) \times n(r)dr$$

with Ecoll(R,r) : efficiency factor
n(r)dr : number of droplets per volume unit having a radius between r et r+dr
u(r) : vertical droplet velocity ($m\ s^{-1}$)

The droplet distribution is simply described as 6 classes. The initial distribution observed for the US-Shuttle was adapted to Ariane 5.

Two other processes have been considered: the evaporation due to the ventilation of the droplet and the eventual fragmentation of the biggest droplets with high speed values. The conclusion is that these two last processes appeared not significant.

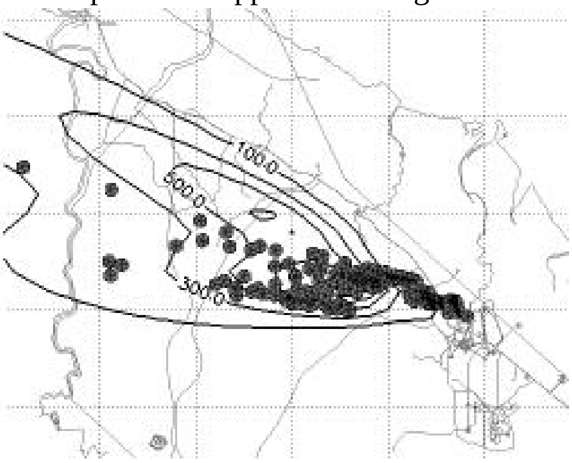


Figure 6: The symbols indicates zone where acid liquid particles are expected

CASE OF FAILURE LAUNCH: SCATTERED SOLID PROPELLANT FRAGMENTS

As a first approach, we have considered every solid fragment as a source and we have generalized the dispersion model applying the model at each fragment. As a function of the height of the vehicles, a table of the gravity centre location, the number and type of pieces allowed to compute a distribution of fragment on the ground. First numerical tests have shown that not taking into account the fusion of plume of the nearest fragments will underestimate dramatically the plume rise. To correct this important bias, we have introduced an algorithm to merge plumes when the fragments are too close. This algorithm consists of computing the stabilized plume for each segment and to evaluate the potential overlap volume ratio. An overlapping threshold was then calibrated using a CFD approach (figure 7). In figure illustrates a case where all the fragments have been substitute by a virtual one with the mass of all the initial fragments.

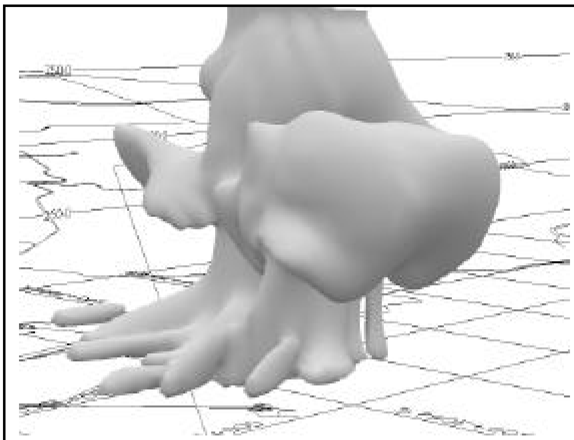


Figure 7: CFD (EDF-MERCURE Code) computation was done to verify how plumes merge and to "calibrate" SARRIM

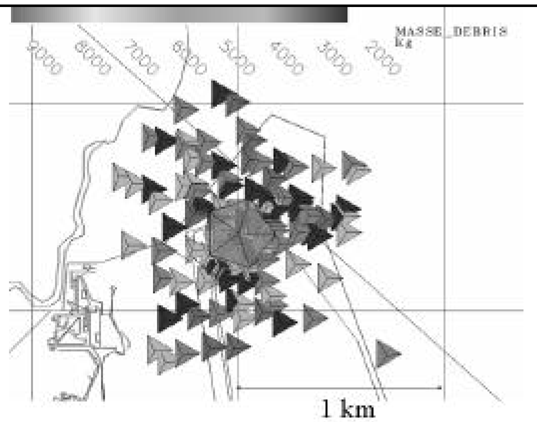


Figure 8: In this example, all the fragments are substituted by only one at the barycentre of the fragments

CONCLUSION AND PERSPECTIVES

SARRIM is a simple and operational model. It is used before every launch and can give answers to the local authorities for many impact and safety assessment questions. The very short CPU time, the limited input data and the powerful graphical process make SARRIM a useful tool.

The comparison with the observations data gives the qualitative evaluation for normal launches:

- Cloud stabilisation height is generally correct, many on-field verifications were done tracking the cloud with an helicopter ;
- For long range computation: concentration, doses and deposition localisation are corrects in regards of the difficulties to get precise measurement (the Al_2O_3 background is high due to the soil composition, nevertheless maxima are generally correctly located ;
- The short range is notably overestimated. New works are undertaken to improve short distance computation.

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