

# Debris impact analysis and mapping results for the rocket vehicle ALV

## Análisis de impacto de escombros y resultados de mapeo para el vehículo rocket ALV

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### ABSTRACT

A risk analysis of the ATK ALV X1 vehicle was developed by the American company ACTA to support the NASA space agency Wallops Flight Facility located in Virginia. This particular risk analysis obtained results of the probability of impact of fragments of this vehicle that could collide with a B747 aircraft that could be flying over the space test area. The ATK ALV X1 was launched successfully but left its nominal flight path trajectory after 27 seconds, and for safety purposes, the flight termination system (FTS) was activated by destroying the vehicle and throwing into space the fragments that endanger air transport. Once again, in space history, ACTA contributes to public and transportation safety in this manner.

**Key words:** ATK, ALV, ACTA, NASA, WFF, risk, trajectory, debris, analysis, impact, aircraft, B747, FTS, fragments

### RESUMEN

Un análisis de riesgo del vehículo espacial ATK ALV X1 fue desarrollado por la compañía norteamericana ACTA para dar soporte a la agencia espacial NASA Wallops Flight Facility, localizado en Virginia. Este análisis de riesgo en particular, obtuvo resultados de probabilidades de impacto de fragmentos o escombros de dicho vehículo que podría impactar sobre aviones B747 que podrían estar sobrevolando el área de prueba espacial. El ATK ALV X1 despegó con éxito, pero salió de su trayectoria de vuelo después de 27 segundos, y por seguridad, el sistema de terminación de vuelo (FTS) fue activado destruyendo al vehículo y lanzando al espacio los fragmentos que ponen en peligro al transporte aéreo. Una vez más, en la historia espacial, ACTA contribuye a la seguridad del público y transporte en este sentido.

**Palabras clave:** ATK, ALV, ACTA, NASA, WFF, probabilidad, impacto, peligro, aviones, B747, FTS, seguridad, riesgo, trayectoria, escombros, fragmentos, análisis

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## Introduction

ACTA was asked to provide additional support to ATK (Alliant Techsystems) and NASA-WFF (Wallops Flight Facility) in preparation for the forthcoming launch of the ALV X1 vehicle. The two areas of support were: (1) updating the toxic risk database due to a change in the trajectory and (2) provide an analysis of the risks to the aircraft from debris resulting from a vehicle breakup.

The purpose of the ATK ALV X1 vehicle was to carry two payloads. The HY-BOLT (Hypersonic Boundary Layer Transition) and SOAREX (Suborbital Aerodynamic Reentry Experiment). The first was designed to cross the atmosphere and evaluate the boundary layer as described by Schetz, J. and Bowersox, R. (2011). The second to characterize a new vehicle for re-entry and innovative self-orientation as described by Eterno, J. (1989). The vehicle was designed to reach a height of 400 km and a speed of approximately 8,500 km / h (Mach number of 8). At this point, the payloads should have been ejected.

For this mission, NASA and ATK hired ACTA to conduct a risk analysis of debris impact on airplanes in order to prevent areas of risk and to take the necessary measures to protect air transport. However, on August 28, 2008, ATK ALV X1 was launched successfully but the ascent lasted only about 27 seconds, and immediately the vehicle began to turn off course, which is why the flight termination system (FTS) was activated

to finish the mission. The results of the risk analysis that ACTA carried out prior to the launch, served to support, and in that sense, prevent disasters due to debris impacts on aircraft flying over the spacecraft's flight area.

## Discussion

Two fragment lists were used for the risk analysis using a program named RRAT. The first list contained Stage 2 debris assuming an explosive failure in the Star 37 Stage 2 solid rocket motor as described by Eterno, J. (1989). This debris list started at the Stage II ignition time of 73 seconds and adjusted at 10 seconds intervals of flight. The second debris list contained a complete fragment list for Stage 1 flight. In this list, the number of fragments in the Stage 2 avionics section due to a Stage 1 explosion was not reduced as it was for Stage 2 failures. ATK pointed out that they have a rather massive aluminum plate above the Stage 2 attitude control system (ACS), defined by Larson, and Wertz, (1992) that shields the avionics pallet and avionics section from direct impact from fragments ejected from a failure/explosion in the lower part of the vehicle.

No malfunction turns were used in the analysis because of the limited time to perform the work. Cross-range dispersions due to guidance uncertainties were provided to ACTA in form of a plot that had results from a Monte Carlo analysis (2000 trajectories) of guidance and performance variation (Figure 1).

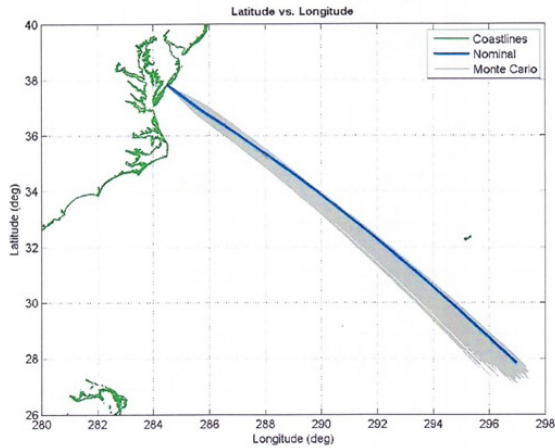


Figure 1. IIP Plots of the Outcome of Many Random Trajectories from the Uncertainty in Guidance and Performance.

Figure 2 shows the impact probability contours for a B747 aircraft flying along a contour. The primary source for the cross-range extent of the contours is the fragment velocities as described by Nelson, Larson, and Arriola, (2007). No malfunction turns were used in the analysis because of the limited time and the cross-range dispersions due to guidance uncertainties were not included either.

The impact probability contours extend downrange approximately 887 NM from the launch pad to the  $1 \times 10^{-7}$  contour level.

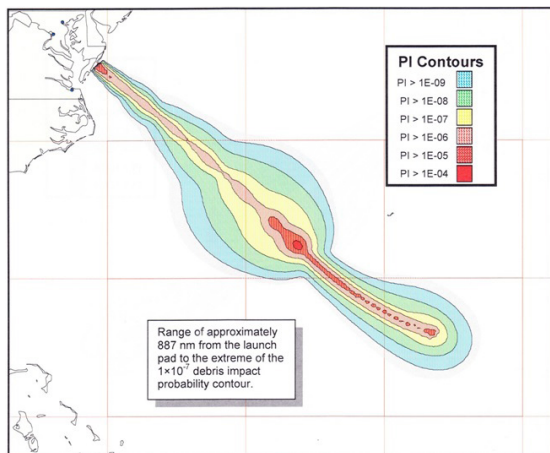


Figure 2. Aircraft (B747) Debris Impact Probability Contours Using No Cross-Range Guidance and Performance Uncertainty or Malfunction Turn Contribution

The impact probability contours during second stage would normally drop off, but this vehicle has a very slow IIP (instantaneous impact point) rate during second stage which produces longer dwell times. Consequently, the higher probability contours persist until the end of flight.

To see if the addition of cross-range uncertainty would change the results, two more plots were prepared: one with a 5 nm one-sigma cross-range variation at burnout and the second with a 10 nm cross-range variation. These two numbers were based on the likely dispersions estimated from the Monte Carlo results in Figure 1. ACTA developed a metric body axis data file (MBOD) for input to RRAT as described by Nelson, Larson, and Arriola, (2007) to capture the cross-range uncertainty in the form of covariance matrices due to guidance and performance error. Figure 3 and Figure 4 show how 5 nm and 10 nm ( $1\sigma$ ) cross range guidance and performance uncertainties affect the impact probability contours.

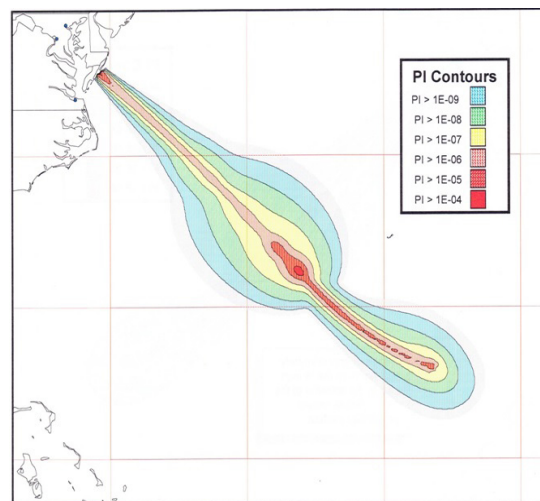


Figure 3. Aircraft (B747) Debris Impact Probability Contours Using 5 nm ( $1\sigma$ ) Cross-Range Guidance and Performance Uncertainty

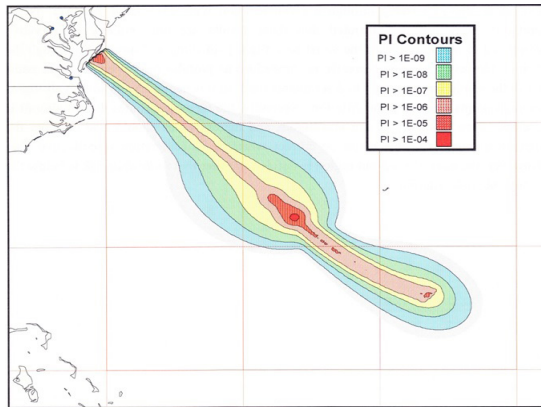


Figure 4. Aircraft (B747) Debris Impact Probability Contours Using 10 nm ( $1\sigma$ ) Cross-Range Guidance and Performance Uncertainty

Comparing Figure 2, Figure 3 and Figure 4, we find very little difference in the dispersions. Thus, we conclude that the dispersion due to fragment velocity dominates. In addition, all three figures have high probability contours all the way to the end of flight. Consequently, it can be concluded that with this debris list, these high failure probabilities and a low accelerating 2<sup>nd</sup> stage, the contours will persist to the impact region.

### Conclusion

Two critiques of the approach depicted in the charts above have

been made, suggesting these results are over-conservative. The results are approximated by assuming aircraft are flying “along a contour” (or equivalently around a grid cell at that point) for the entire duration that debris is a hazard at that altitude. A first critique is that aircraft quickly pass through the region, so are not exposed to the entire duration of debris. While it is true that most aircraft passing through a given location will be exposed to lower risk, a previous study has demonstrated that these results are only slightly conservative compared to an aircraft with the worst-case flight path (time and direction) through the point. However, there is currently no procedure to prohibit only specific flight paths (with the resolution necessary to discriminate this), so it is necessary to prohibit all flights through points exceeding the criterion. Secondly, the method assumes that an aircraft is present, when in fact, there are few flights, and therefore one should consider the density of aircraft. This could be correct when the consideration is collective risk. However, the aircraft keep-out region is defined in order that individual risk is below the acceptable risk criterion.

### References

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