ORBITAL DEBRIS : A CASE STUDY OF AN IMPACT EVENT IN SOUTH AFRICA.

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ABSTRACT/RESUME

On 27 April 2000, around 15:30 South African Standard Time (SAST), three pieces of space debris impacted at three separate locations in the western Cape.

Each impact, impact location, eyewitness reports and subsequent events are described briefly. Examination and identification of the space debris that survived the rigours of re-entry are detailed. Some images of the surviving debris, which, in general, suffered only moderate damage as a result of the re-entry process, are provided.

These events underline the potential danger of space debris to man, his activities and infrastructure. Although there were no casualties or extensive damage in this case, all three impact sites are close to densely populated areas and other sensitive infrastructure where serious damage and casualties may have resulted.

The danger that orbital debris poses to man's terrestrial and space infrastructure and activities over the long term is considered.

1. SUMMARY:

On 27 April 2000, around 15:30 South African Standard Time (SAST), three pieces of space debris fell in three separate locations in the western Cape. The first, a large cylindrical stainless steel tank, fell on a dairy farm near Durbanville, the second, a titanium sphere, about 70 kilometres further to the east south east in the vineyards of a farm near Worcester and the third, a conical section of a combustion chamber-exhaust nozzle made of composite materials, another 23 km further east south east, also in the vineyards of a farm near Robertson. Eye witnesses to these events agree that these objects were travelling very fast, descending from the West at an angle and were still white or red hot after impacting the ground. They also reported that they heard sounds described as a roll of thunder, a loud crack, explosions and rifle shots associated with the impacts . Other eye witnesses to the south of the impact trajectory reported three trails of light moving very rapidly a roll of thunder and explosions.

Subsequently it was established with a fair degree of certainty, that the three pieces of space debris were the remains of a DELTA II second stage rocket that re-entered the atmosphere (± 100 km high) over the South Atlantic, at approximately 15:18 SAST, while heading towards South Africa. This DELTA II second stage was part of a DELTA II launcher used to place a GPS (Global Positioning System) navigational satellite in orbit for the United States Air Force, on 28 March 1996.

Incidents involving three separate pieces of space debris impacting in three different locations were reported.

2. NATURE, LOCATION AND TIME OF IMPACT OF SPACE DEBRIS:

Based on the many reports in the local media there is no doubt about the nature of, and locations where, the space debris fell in the western Cape. The approximate time of impact is more difficult to determine from local media reports which initially indicated that the space debris fell on different days at more or less the same time. Subsequently it was determined beyond reasonable doubt that all three pieces of space debris fell on Thursday 27 April at around 15:30 SAST.

The approximate locations where the space debris impacted in the western Cape are marked on the map in Fig. 1, [1] below.

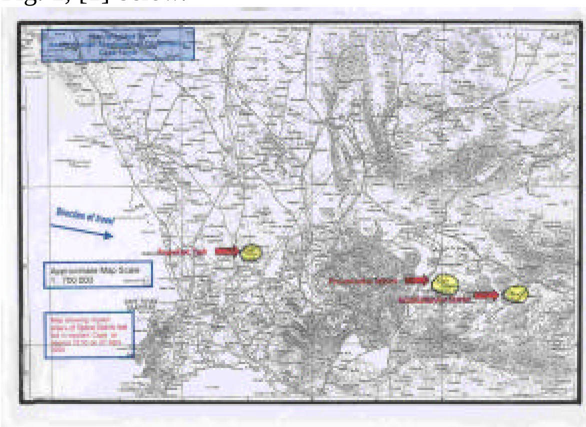

Fig. 1. Map showing approximate locations. of space debris impact sites.

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As can be seen from the map above, the largest steel tank-like object impacted near Durbanville, the metal sphere some 70 km further near Worcester and the composite material cone-like object another 23 km further near Roberson. These three pieces of space debris were photographed in the mechanical workshops of the South African Astronomical Observatory (SAAO), Observatory Cape Town and are shown in Fig. 2, [2] below.

Fig. 2. Three pieces of space debris that impacted in the western Cape photographed in mechanical workshops of SAAO, Cape Town.

The sequence in which the debris impacted could not be determined from local media reports, which is hardly surprising. Originating from the same "parent object" and travelling at great velocities it is likely that time of impact between the first and the last impact would be close. Conventional wisdom will have it, that the object found closest to the point of re-entry probably impacted first, whereas the object found furthest from the point of re-entry, impacted last. This assumption was confirmed by Dr Nicholas L Johnston, Chief Scientist and Program Manager of the Orbital Debris Program Office at NASA's Johnson Space Centre. Commenting on local media reports that reported all three impacts occurred at about 15:30 SAST, Dr Johnston said that the time elapsed between the first impact in Durbanville and the last in Robertson could possibly be as little as 4 minutes. If this was the case it meant that the debris could have been travelling at some 1400 kph in the terminal phase of it's re-entry trajectory! The "explosions" and "gun shots" and "roll of thunder" heard by eye witnesses of the impacts seems to be consistent with objects travelling in the atmosphere at supersonic velocities.

2.1 <u>The "Durbanville" Space Debris</u>.

The largest of the three pieces of debris recovered, impacted on a dairy farm near Durbanville. According to local media reports time of impact was around 15:30 on Thursday afternoon 27 April 2000.

This object is a cylindrical stainless steel tank some 2.7 metres long, 1.5 metres in diameter and weighing approximately 260 kilograms. This tank suffered significant damage and deformation during re-entry and subsequent impact with the ground. The tank has two hemispherical sections on either side of the cylinder one of which has a hole, some 30cm diameter. It is apparent that another object (probably the second stage liquid fuelled rocket motor) was securely attached to it with a large number of (29) bolts. See Fig. 2.

It is apparent that the some of the peripherals attached to the stainless steel tank, melted during re-entry as bright metal (probably aluminium) can be seen smeared against the stainless steel tank on several places. See Fig. 3, [3] below.

Fig. 3. Metal smears (probably aluminium) visible on stainless steel tank.

On closer inspection a diaphragm was observed in the stainless steel tank probably to provide separate containers for the propellant and the oxidizer used in the liquid fuelled rocket motor attached to this stainless steel propellant tank.

During its four year sojourn in low earth orbit the stainless steel tank suffered a number of space (orbital) debris or micro-meteorite impacts. Careful inspection of the surface revealed a number of small impact craters. One of these is shown in Fig. 4, [4] below.

Fig.4. Impact crater on stainless steel propellant tank.

Eye witnesses reported that they saw a "glowing ball" moving very rapidly falling to the ground some kilometres away on a neighbouring farm. They heard a loud crack followed by an explosion. This could have been caused by the fact that the object was moving at supersonic speed before impacting the ground. They set out to search for it and found the stainless steel tank two hours later. It was still hot.

During a subsequent visit to the site on 17 May 2000, the point of impact could not be located in the short time available. It is believed that the stainless steel tank impacted the ground at a shallow angle, and probably bounced, rolled and tumbled for a considerable distance over the flat terrain, before finally coming to rest. The sparse grass in the area where the stainless steel tank was found, and for some distance to the west, was clearly subjected to a great deal of heat

As can be seen from Fig. 5, [5] below the area of impact is in a very sparsely populated area.

Fig.5. The man in the image is standing next to the spot where stainless steel propellant tank was recovered.

The stainless steel propellant tank was eventually taken to the Kraafontein Police station for safekeeping, from where it was transported to the mechanical workshops of the South African Astronomical Observatory (SAAO), in Observatory, Cape Town.

2.2 The "Worcester" Space Debris.

A metal sphere impacted the ground in the vineyards of the farm "Lemoenpoort" near Worcester at approximately 15:30 on Thursday 27 April 2000. This spherical metal object is some 60 centimetres in diameter and weighs approximately 33 kilogram. See Fig. 2.

According to workers, a glowing white hot ball travelling very fast came "from nowhere" and impacted the ground in the vineyards on a neighbouring farm nearby making a 20 cm deep impression. It did not come from right above but at a shallow angle. What sounded like two gunshots were reported when the sphere impacted. As in the case of the stainless steel tank that impacted near Durbanville, the gunshot-like noises could possibly be associated with supersonic speed at which the sphere was travelling before impact. The sphere was still to hot to handle when owner of the farm arrived half an hour later, but it was subsequently transported to his barn for safekeeping.

After reading media reports the Department of Civil Aviation at Cape Town International Airport requested the Worcester police to collect the sphere for their inspection. They suspected that it might have originated from an aircraft.

The metal sphere was eventually secured by ersonnel of the SAAO, and transported to their mechanical workshops in Observatory, Cape Town (Fig. 2).

2.3 The "Robertson" Space Debris.

A tapered cylindrical pipe like object weighing some 30 kilograms, impacted the ground in a vineyard on the farm "De Wilgen", near Robertson around 15:30 on Thursday 27 April 2000. This object is approximately 60 cm long, 30 cm diameter at the "base" and 20 centimetres at the "apex". It is made from non-metallic (probably composite) materials (Fig. 2). The force of the impact is reported to have made a 15 cm deep hole in the ground. This object may have formed part of a larger structure that probably disintegrated during re-entry.

Eye witnesses to the final stages of the decent said they saw a tumbling object moving very fast making a "woor woor" noise similar to the rotor blades of a large helicopter landing. The object impacted the ground with a dull thud, in a vineyard on the neighbouring farm some 200 metres from them. They went over to investigate and found the smoking very hot object described above. It was still spluttering metal and what appeared to be rubber (similar to that found in motorcar tyres) was still burning at one end of the object. The matter was reported to the police as it was suspected that it could be part of an aircraft landing gear, without which the aircraft could not land safely. Subsequently the Robertson police fetched the object.

Eventually the pipe like object was collected by personnel from the SAAO and transported to their mechanical workshops in Observatory, Cape Town (Fig. 2).

3. IDENTIFICATION OF THE SPACE DEBRIS THAT FELL IN THE WESTERN CAPE AROUND 15:30 ON THURSDAY 27 APRIL 2000.

Based on inspection of the space debris in the workshops of the SAAO, in Cape Town, (Fig. 2) the many media reports, imagery supplied by Dr Johnston and obtained from The Aerospace Corporation, Aerojet and SAAO web sites composite comparative images could be generated. Visual comparison of the "Western Cape" and "Texas" space debris, the latter identified as originating from a DELTA II second stage, show remarkable similarities. These comparisons leave little room for doubt as to the origin of the space debris that fell in the western Cape, as can be seen in Fig. 6, [6] Fig. 7 [7] and Fig. 8, [8] below.

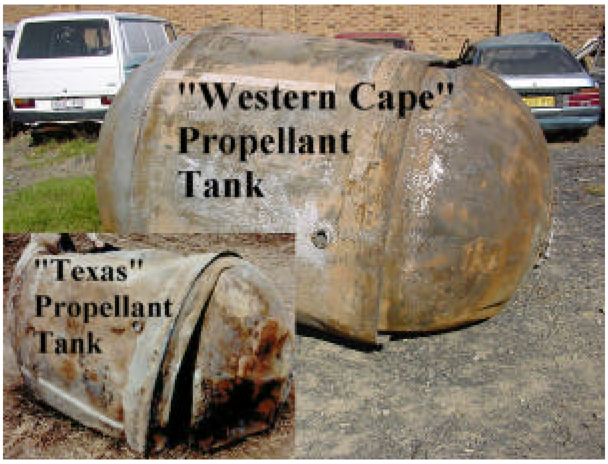

Fig. 6. Composite image of the propellant tank that impacted near Durbanville in the western Cape and the DELTA II second stage propellant tank that impacted in Texas on 22 January 1997. Similarities are obvious.

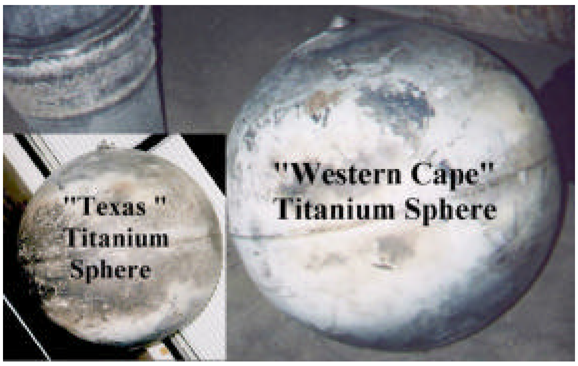

Fig. 7. Composite image of the titanium sphere that impacted near Worcester in the western Cape and the DELTA II second stage titanium sphere that impacted in Texas on 22 January 1997. Similarities are obvious.

Fig. 8. Comparative image of the DELTA II second stage thrust chamber that impacted in Texas on the left, and thrust chamber that impacted near Robertson in the western Cape on the right. Similarities are obvious

4. CONCLUSIONS

There can be little doubt that the space debris that impacted in the western Cape on 27 April 2000 and in Texas on 22 January 1997 originated from similar DELTA II second stages. An E-MAIL received from Dr Johnston in response to a query relating to the possible origin of the space debris that fell in the western Cape provided additional compelling circumstantial evidence that the space debris that fell in the western Cape originated from a DELTA II launcher second stage:

"As most of the South African media has correctly reported, the parent object was a DELTA 2 second stage used to launch a U.S. GPS satellite on 28 March 1996. The international designator was 1996-019B, and the U.S. Satellite Number for tracking the object was 23834. Atmospheric interface (typically about an altitude of 80-100 km) occurred at approximately 1318 UTC (15:18 SAST) on 27 April over the South Atlantic".

In view of the information from local and authoritative sources in the United States there is little doubt that the space debris that fell in the western Cape on 27 April 2000 at around 15:30, originated from a DELTA II second stage that re-entered the earth's atmosphere over the south Atlantic on its way to South Africa..

According to Dr Johnston there are a number of other peripherals on the DELTA II second stage, such as pressure tanks etc. that will probably survive re-entry. See Fig. 9, [9] below. It is therefore quite possible that there may be some more pieces of space debris in the general area where the three pieces were recovered in the western Cape.

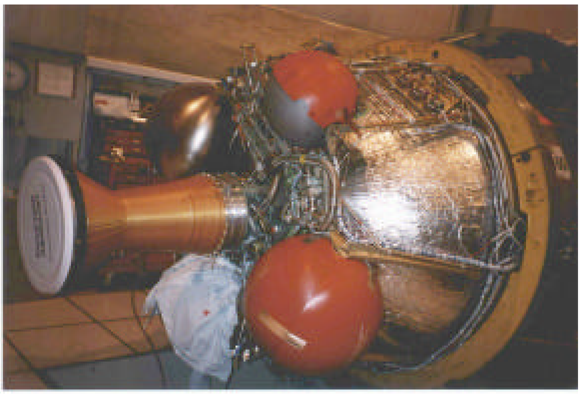

Fig. 9. DELTA II second stage before integration into DELTA II launcher. Three other spheres somewhat smaller the one that impacted near Worcester in the western Cape can be seen.

There were no casualties, injuries or significant damage as result of the three separate space debris impacts in the western Cape on 27 April 2000. However as can be seen from the size and weight of the objects, they have the potential of causing considerable damage in built-up areas because of the speed with which they impact the ground and because they are white hot at impact as result of atmospheric friction during re-entry.

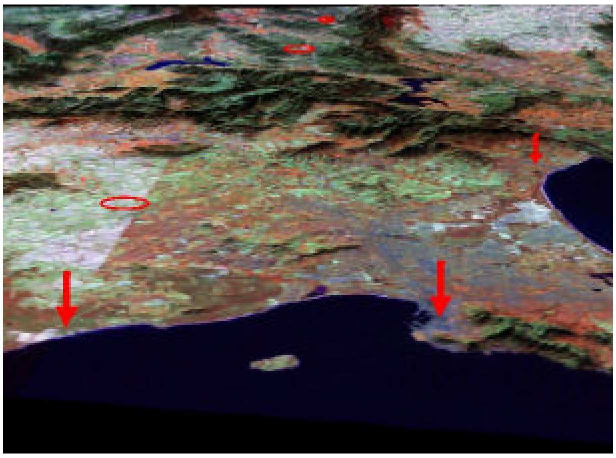

Fig. 10, shows a perspective view of the Cape Peninsula area. The red ellipses indicate the space debris impact sites. The red arrows (from left to right) the location of the Koeberg nuclear power station, Cape Town city and Sonchem , a manufacturer of commercial explosives and propellants for military applications.

If one looks at the perspective view of the Cape Peninsula in Fig. 10, [10] above generated by draping a LANDSAT 5 TM (Thematic Mapper) scene over a Digital Elevation Model (DEM) of the area, from a vantage point south of the re-entry trajectory of the space debris that impacted the area, a number of interesting observations can be made. The impact areas are indicated by red ellipses decreasing in size to the east, south east.

The red arrows (from left to right) indicate the location of Koeberg, South Africa's only nuclear power station, down town Cape Town and the Cape Town harbour and the Sonchem installations near The Strand. Sonchem produces commercial explosives and a variety of propellants and explosives for military applications.

Koeberg and Cape Town are approximately 20 km from the propellant tank impact location, and the Sonchem installations some 40 km. It is not inconceivable that any of these locations may have been hit by the 250 kg white hot stainless steel propellant tank, or some of the other debris from the DELTA II second stage, with potentially disastrous consequences

It is interesting to note that in 1979 there was a similar incident of space debris impacting in the Cape Province [11]. Two metal spheres were found on the farm "Kransfontein" in the Kouga mountains. Eye witnesses in the nearby small town of Joubertina reported that they saw three bright streaks of light followed by a loud bang and "an unearthly rumble". It was reported that the spheres found had a diameter of some 50 cm. Since DELTA launchers have been in service since 1960, and the second stage, powered by the same Aerojet AJ10-118K liquid fuelled rocket motor, used since the mid seventies, the question arises if these metal spheres perhaps originated from and earlier DELTA launcher second stage. No damage or casualties were reported at the time.

5. SPACE DEBRIS. THE FUTURE . . . . ?

The problem of space (orbital) debris originated on 4 October 1957 when Sputnik 1, was launched into orbit from the Baikonur Cosmodrome in Russia. Although the sojourn of Sputnik 1 and the final stage that placed it in orbit in space, was only a few months, it marked the beginning of man's pollution of space and problems associated with space (orbital) debris.

Orbital (space) debris is defined as any man made object in orbit which no longer serve a useful purpose. According to the Space Science Branch of NASA's Johnston Space Centre [12] the orbital (space) debris population is enormous. More that 9000 objects with one of it's dimension larger than 10 centimetres are known to exist. Estimates of the number of fragments with one dimension between 10cm and 1 cm are as high as 100 000 and fragments smaller that this may run into millions . It is certain that as space activities continue these numbers will continue to increase.

Explosions of on-board energy sources (leftover propellant and batteries) in non-attitude controlled spacecraft and final launch stages after their functional life time, and deliberate destruction of spacecraft compound the problem by producing "clouds" of new debris. Since only earth orbiting space debris below some 600 to 700 km will eventually decay and re-enter the earths atmosphere the density of space debris at higher altitudes will increase steadily in future.

Communications, navigation and earth observation (to name but the most obvious) infrastructure provided by satellites have become an integral and indispensable part of modern civilisation. It is safe to assume that role of these satellites in man's everyday activities will become even greater in the future as the "Global Village" develops.

In spite of technical progress and innovation the geo-synchronous, and to a lesser extent low sun-synchronous, polar orbital region represent finite resources that will, in time to come, become saturated. All satellites launched in the future will have to share these orbits with existing space (orbital) debris.

Although space debris large enough to damage terrestrial infrastructure can be tracked relatively easily, it is not clear what effective steps can be taken, even if adequate warning is provided of the impending re-entry and probable area of impact.

From the forgoing it is clear that the ever increasing space (orbital) debris density, especially in useful orbits, poses a serious problem for man's future activities in space. The concomitant light pollution will eventually impact ground based astronomical observations.

It will be in mankind's interest to limit the generation of space debris during all future space missions. In addition attention will have to be given to controlling the location of the re-entry impact of large pieces of space debris. Although the chances of impacting sensitive terrestrial infrastructure is small, it is only a matter of time before this happens, as the "near miss" in the western Cape impact event on 27 April 2000 illustrates.

6. REFERENCES

1. Map showing approximate locations of impact of space debris supplied by Mr. C Rijsdijk of SAAO.

2. Photograph of space debris in SAAO mechanical workshop supplied by Mr. C Rijsdijk.

3. Image of metal smears on stainless steel propellant tank provided by Mr C Rijsdijk of SAAO.

4. Image of micro-crater in stainless steel propellant tank provided by Mr C Rijsdijk of SAAO

5. Image of location where stainless steel propellant tank was fond taken by W J Botha of CSIR.

6. Composite image of stainless steel propellant tanks produced by W J Botha of CSIR from images obtained on the SAAO and Aerospace Corporation Websites.

7. Composite image of titanium pressurisation sphere produced by W J Botha of CSIR from images obtained on the SAAO and Aerospace Corporation Websites.

8. Comparative image of the DELTA II second stage thrust chamber produced by W J Botha of CSIR from image on Aerospace Corp. website and photograph by Mr. A. Robertson of "Die Burger" daily newspaper.

9. Image of DELTA II Second stage before integration into the launcher provided by Dr Nicholas L Johnston, Chief Scientist and Program Manager of the Orbital Debris Program Office at NASA's Johnson Space Centre.

10. Perspective of western Cape area showing space debris impact points and sensitive terrestrial infrastructure produced by Mr. W Voster of the Satellite Applications Centre, CSIR.

11. Report in "Die Burger" daily newspaper dated 1 May 2000.

12, Information from Frequently Asked Questions on website of the Orbital Debris Program Office at NASA's Johnson Space Centre.

7. ADDITIONAL SOURCES OF INFORMAQTION

1. News letter of the South African Astronomical Observatory at http://www.saao.ac.za/news/debris.html

2. Boeing web page: http://www.boeing.com

3. Aerojet web page: http://www.aerojet.com

4. Johnson Space Centre Space Science Branch web page: http://sn-callisto.jsc.nasa.gov/

5. Aerospace Corp. web page. http://aero.org