LA-UR- 96: 2792

Title:

**DISCUSSION OF "REVIEW OF 'SPACE
DEBRIS HAZARD TO DEFENSE
SYSTEMS'"**

Author(s):

Gregory H. Canavan, DDP

RECEIVED
SEP 09 1996
OSTI

Submitted to:

For discussions outside the Laboratory

Date: August 1996

MASTER

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Form No. 836 R5
ST 2629 10/91

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

RB

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Discussion of "Review of 'Space Debris Hazard to Defense Systems'"

Gregory H. Canavan

This note discusses the "Review of 'Space Debris Hazard to Defense Systems'" by the NASA Johnson Space Center (JSC), which are referred to below for brevity as the "Review" and *Space Debris Hazard*, respectively. JSC has also prepared a "Detailed Review of 'Space Debris Hazard to Defense Systems'," which is commented on in a separate document.

The JSC Review's points are addressed in the order in which they are presented. Their first paragraph of the Review states "Mr. Canavan was unable to provide copies of the three Canavan papers and the one Judd paper listed as references in his paper." There are only two papers by the author; the third was an *op. cit.* to the first. The other reference was to Dr. Judd's presentation at JSC, of which JSC has the only record.

The first two papers were requested of the author and Dr. Judd by Mr. Kessler when they visited JSC on 16-17 August and 16-17 October 1995. Dr. Robert Naka stated that the reports would not be released until the Air Force Scientific Advisory Board (SAB) study was completed. Mr. Loftus again requested these *two* reports on 11 June 1996,¹ and was again informed

"the two notes you request were written for the SAB, so I do not control their release until after the report is released, as explained to Dr. Kessler earlier. It was to have been completed before Space 96, but it should be out shortly. I will ask our chairman about their release."²

As the authors do not have the authority to release these reports, the proper channel for requesting them has been explained, and JSC has apparently made no request through those channels, it appears that no action is required on this item at this time.

JSC's **Summary** "Review" does not correspond to *Space Debris Hazard* its "essential points," which JSC characterizes by four statements:

1. The JSC Review states that an essential point of *Space Debris Hazard* is that "The NASA JSC model overestimates the debris population at Shuttle and Space Station altitudes by about an order of magnitude."

Space Debris Hazard demonstrates that using the Haystack data to which the JSC model has now been "updated"] "gives a collision time of 300 years, or a 3% probability of impact per decade of habitation," which is not questioned in JSC's Summary or Detailed Reviews. The JSC model³ overestimated the Haystack debris flux by about an order of magnitude, which has now apparently been corrected, leaving *Space Debris Hazard's* statement unchanged.

The JSC Review states that "The conclusion drawn from this is that efforts to shield the Space Station may be unnecessary."

Space Debris Hazard does draw no conclusion about additional shielding, although the Review's observation that it "may be unnecessary" is perhaps appropriate, given the impact rates above, on which there is now closer agreement.

2. The JSC Review states that an essential point of *Space Debris Hazard* is that "The Haystack radar data cannot be interpreted to yield valid debris object sizes."

Space Debris Hazard does *not* state that "...Haystack radar data cannot be interpreted..." It shows that the data "cannot be interpreted by the procedure *used by JSC* to "determine the size or distribution of the scattering objects uniquely," for reasons discussed below.

3. The JSC Review states that an essential point of *Space Debris Hazard* is that "Impacts at high altitudes will reduce the lifetimes of satellites only slightly."

Space Debris Hazard does *not* assume that "Impacts at high altitudes will reduce the lifetimes of satellites only slightly." It uses JSC's interpretation of Haystack data to show that

1. J. Loftus, JSC email to G. Canavan, 11 June 1996.

2. G. Canavan, Los Alamos email to J. Loftus, 12 June 1996.

3. E. Stansbery et al, "Haystack Radar Measurements of the Orbital Debris Environment," NASA Report JSC-26655, 20 May 1994.

impacts by the 1 cm and larger particles discussed⁴ by JSC would reduce DoD satellites' 10 year lifetimes about 1%, which is a "small effect compared to other factors considered in their amortization," as stated.

The JSC Review states that "This effect is considered to be of no significance for spacecraft design and operation."

Space Debris Hazard made those corrections specifically so that the correct impact rates could be used in design and operation.

4. The JSC Review states that an essential point of *Space Debris Hazard* is that "The NASA models greatly overestimate the yield of fragments from on-orbit collisions."

Space Debris Hazard does *not* state that "NASA models greatly overestimate the yield of fragments from on-orbit collisions." It states that "JSC models replace calculations and measurements of the *average* number of fragments from *collisions* with the *maximum* number of fragments observed from *explosions*," as discussed by Drs. Naka, Judd, and Canavan with Mr. Kessler,⁵ which increases the number of fragments per collision by a factor of 6 to 10. Mr. Kessler again advocated this substitution in subsequent correspondence⁶

"Concerning the number of fragments produced as the result of a collision that are large enough to be capable of breaking up another satellite...These two data points [P78 & Delta 180] would support the idea of *using the 10 most energetic explosions as data points for the number of large fragments produced*. Looking at the large population alone, it is *difficult to tell the difference between a collision and an explosion* (emphasis added)."

To the extent large collisions are substituted for average collisions, the JSC models overestimate the yield of fragments from on-orbit explosions by about an order of magnitude, as stated.

The JSC Review states that an essential point of *Space Debris Hazard* is that "More reasonable estimates of the fragment yield from collisions show that the doubling time for cascading could be as long as 2,000 years, if indeed, collisional cascading ever occurs."

Space Debris Hazard shows that the primary difference between JSC's ≈ 240 year doubling time and *Space Debris Hazard's* $\approx 2,000$ year doubling times for collisional cascading is JSC's use of the maximum fragments per explosion rather than the average fragments per collision, which is smaller by a factor of six to eight. Mr. Kessler agreed to this assessment, stating that "cascading was not a problem" so that JSC was "only concerned about the possible linear growth due to increased launches and explosions."⁷

The JSC Review states that an essential point of *Space Debris Hazard* is that "The NASA models that assume a continuation of current launch and explosion rates overestimate the growth of debris. Air Force projections for launch and explosion rates do not support growth of the debris environment at rates predicted by NASA."

Space Debris Hazard does *not* state that "NASA models that assume a continuation of current launch and explosion rates overestimate the growth of debris." It states that DoD, NASA and interagency studies that project launch rates into the next century do not "support growth of the debris environment at the rates predicted by NASA [JSC]," as discussed below.

The JSC Review states that "The conclusion drawn from these factors is that efforts to remove spent upper stages and satellites from orbit are unnecessary."

Space Debris Hazard makes *no* mention of removing spent upper stages and satellites, although that now appears to be the principal thrust of proposed JSC efforts, in contrast to JSC's

4. R. Reynolds and P. Eichler, "Future Debris Environments Using the Evolve and Chain Programs," NASA JSC, 17 August 1995.

5. D. Kessler, "Models of the Current LEO and GEO Environment" and discussion, NASA JSC. 16-17 August, 1995.

6. D. Kessler, email to G. Canavan, 12 June 1996.

7. D. Kessler, "Models of the Current LEO and GEO Environment" op. cit.

emphasis over the last three years on the reduction of fragments and operational debris, as briefed last year.⁸

The JSC Review's **Counter Points** provide additional information, discussed below:

1. The JSC Review states that "The author used an out-of-date debris environmental model (ORDEM89)..."

Space Debris Hazard used the charts JSC briefed and used to compare the JSC model and Haystack data.⁹ The author pointed out at the time—using model and Haystack impact rates read directly from JSC's figure—that the model disagreed with the Haystack data by an order of magnitude. Then and subsequently, he requested any revisions of the model or data; none have been provided by JSC to date.¹⁰

The JSC Review states that "NASA updated the old model during 1995 to produce the ORDEM96 model, which is based on Haystack data and consistent with it."

Space Debris Hazard had the advantage of Mr. Kessler's further explanation:

"The differences between the "NASA model" and the Haystack measurements are now not as great as when your were here...An *error* was found in Gene Stansbery's computer program which used the NASA model to predict what Haystack should see. The error was in indexing the altitude bands...Gene assigned a model prediction altitude band that was 50 km too low. Therefore, all of the NASA model predicted count rates are too high, *especially those at lower altitudes.*"¹¹ (emp. added)

Thus, the revision involved more than an "update." ORDEM89 was wrong; hopefully, ORDEM96 is better, although from the discussion in the next section, it is not clear that introducing the Haystack data represents a step forward.

It is surprising that JSC states, as it does in the Detailed Review of this point (no. 11), that "This result [the correction of an order of magnitude error in its threat model] is of no real significance, since we have updated our engineering model during 1995." If the previous year's results are discarded every time a new set are computed, it will never be clear whether it represents a step forward.

The statement by Mr. Kessler repeatedly referred to the JSC model as the NASA model. As a practical matter, that is now the case. The Haystack data and the JSC model have been carried over directly into the recent books on *Orbital Debris* by the National Research Council of the National Academy of Science (NRC/NAS)¹² and the *Interagency Report on Orbital Debris 1995* by the Office of Science and Technology Policy (OSTP).¹³ Thus, an important question is the extent to which the order of magnitude reduction in the threat from ORDEM89 ORDEM96 has reduced the threat communicated by those models to the NRC, OSTP, and satellite builders.

2. The JSC Review states that "The author suggests that the method used to compute debris sizes from radar cross section data measured by the Haystack radar is faulty, in that it cannot yield unambiguous results. In doing so, he contradicts the opinion of a panel of the nations' leading radar experts..."

Space Debris Hazard does *not* state that the Haystack "cannot yield unambiguous results," only that the data "cannot be interpreted by the procedure JSC uses to "determine the size or distribution of the scattering objects uniquely." Radar cross sections vary orders of magnitude with both fragment diameter and orientation. Haystack has observed only a fraction of

8. R. Reynolds and P. Eichler, "Future Debris Environments Using the Evolve and Chain Programs," op. cit.

9. E. Stansbery et al, "Haystack Radar Measurements of the Orbital Debris Environment," op. cit., p. 49, Fig. 5.4-2.

10. G. Canavan, email to D. Kessler, 20 March 1996.

11. D. Kessler, email to G. Canavan, 19 March 1996.

12. G. Cleghorn, *Orbital Debris* (Washington, National Research Council, 1995).

13. *Interagency Report on Orbital Debris* (Washington DC, Office of Science and Technology Policy, 1995)

the objects larger than a centimeter—almost none from more than one angle. The size of such objects cannot be determined from a single observation at a single orientation, so the interpretation of the JSC Haystack data is indeterminate. Taken at the right frequency, the JSC "representative data base," would be relevant, if the objects on orbit were observed from many angles, *which they are not*. JSC cited but did not provide the analysis of this problem by its contract "panel of experts." It would be useful to have an independent DoD panel of radar experts review it to see if valid inferences can be made from the data.

The JSC Review states that "The author also states that the Haystack data do not agree with the catalog in the region where they overlap. This is incorrect, as shown in the recent Haystack report."

Space Debris Hazard notes that the Air Force Space Command (AFSPC) Catalogue is only complete for objects larger than about 30 cm, at which the one standard deviation variance assigned by JSC to the 400 km Haystack data extend from 2×10^{-8} to $4 \times 10^{-7}/\text{m}^2\text{-yr}$, which is about a factor of 20.¹⁴ A flux of $10^{-7}/\text{m}^2\text{-yr}$ is attributed by JSC to the Catalog of debris ephemerides maintained by AFSPC, *which does not produce estimates of fluxes*. That this mean value lies within the factor of 20 JSC's variance in JSC's Haystack fluxes is meaningless, since the variance is an order of magnitude larger than the mean value.

3. The JSC Review states that "The conclusion that collisions at high altitudes will affect the lifetimes of satellites only slightly is based on the author's result that losses will amount to only 1% over a ten year period for typical satellites. There is an unstated assumption in this conclusion, which is that only 1 cm particles will disable a spacecraft. "

Space Debris Hazard's conclusion that "collisions at high altitudes will affect the lifetimes of satellites only slightly " is an observation based on the impact rate for 1 cm particles presented by JSC. Neither the JSC Summary or Detailed Reviews takes exception to *Space Debris Hazard*'s "1% over a ten year period" estimate.

The JSC Review states that "The weight and volume of shielding required to protect a spacecraft from impact by 1 cm particles is prohibitive for many missions. If impact by a 0.5 cm particle is assumed to disable a spacecraft, then the loss rate rises to 9% over ten years."

Space Debris Hazard notes that the relative shielding penalty scales as the ratio of area to volume, which decreases for the large satellites discussed here, so shielding of 1 cm is not necessarily "prohibitive," unless shielding against JSC's 0.5 cm particles is "half prohibitive." It is likely that millimeter particles would impact more frequently, but they have not been measured directly, and Haystack estimates of their fluxes are uncertain for the reasons discussed above. JSC's failure probabilities are based on assumed values for those impact rates.

4. The JSC Review states that "The conclusion that NASA uses extreme values for the number of fragments produced in an on-orbit collision arises from that (sic) fact that NASA uses a larger value for the most probable collision mass than the author does.

Space Debris Hazard had access to Mr. Kessler's statement that JSC uses "the 10 most energetic explosions as data points for the number of large fragments produced," which is *independent* of the average mass of the actual colliding partners.¹⁵ Moreover, *Space Debris Hazard* assessed the sensitivity of the number of fragments per collision to the average mass and found it to be weak.

The JSC Review states that "In fact the breakup models used by the author and NASA give approximately the same answer for the same mass of colliding objects.

Space Debris Hazard shows that this statement is only correct if "approximately" is interpreted to mean "within about a factor of 10." JSC uses 480 fragments per collision; *Space Debris Hazard* calculates 60 to 80 fragments per collision; their ratio is a factor of 6 to 8, as stated. The breakup model used by *Space Debris Hazard* is in accord with the number of fragments from DoD railgun experiments, Atlas tests, and average on-orbit explosions. JSC's

14. E. Stansbery, et. al., "Haystack Radar Measurements of the Orbital Debris Environment," NASA JSC-26655, May 20 1994, op. cit., p. 49, Fig. 5.4-2.

15. D. Kessler, email to G. Canavan, 12 June 1996.

value is an extreme, whose origin is unclear. It is difficult to compare calculations of the masses of colliding objects, as JSC's calculations are not documented; only the results are stated.¹⁶ Thus, it is not clear which breakup model the Review cites for JSC or attributes to Space Debris.

The JSC Review states that "The author obtained an incorrect value for the most probable collision mass by neglecting the cross-sectional areas of the colliding objects. His result is about a factor of three below the result derived from detailed statistical calculations using the real masses and sizes of objects currently in orbit."

Space Debris Hazard included the cross-sectional areas of colliding objects. However, there is an order of magnitude more smaller catalog objects than large spacecraft and rockets, so collisions with the smaller objects dominate collisions with the latter, reducing the effect of projectile cross section to a 20-30% effect. No basis or reference is given for the "factor of three," so no comment is possible. *Space Debris Hazard* performed statistical calculations using the real "sizes of objects currently in orbit," which did not alter these results significantly.

JSC states that it uses "the real masses...of objects currently in orbit," (emp. added) and in the Detailed Review, JSC elaborates that its estimate of the mass in orbit "is based on the objects known to be in orbit according to the USSPACECOM Catalogue, and not on the difference in inventories of the launched and decayed material." However, the USSPACECOM (AFSPC) Catalogue does not contain masses; it only contains radar cross sections, and the cognizant organizations in those Commands have indicated that they do not know how to relate the two accurately. Thus, it would appear that the masses used in JSC's calculations are known no more directly than those used in *Space Debris Hazard*.

The JSC Review states that "By using this incorrect value, [*Space Debris Hazard*] underestimates the number of the fragments resulting from collisions relative to the number calculated by NASA. As a consequence of this error, he considers collisional effects to be of no consequence for the periods up to 2000 years. The author also misses some important points concerning collisional cascading effects... it may be some time after critical density is reached before collisional processes become dominant."

Space Debris Hazard calculated the number of fragments per collision; JSC assumed a larger number. The 2000 years is the direct result of a calculation of the doubling time for collisional cascade using measured rates. The basis for JSC's estimate is less clear. The fundamental reason for debris growth by collisional cascading "to be of no consequence for periods up to 2000 years," rather than JSC's 240, is JSC's use of "the 10 most energetic explosions as data points for the number of large fragments produced," which reduces the doubling time by that amount, as discussed above. The further reduction to a few decades is due to JSC's projection of high historic launch rates to LEO into the next century, which does not agree with projections discussed below. *Space Debris Hazard* does not need to make use of JSC's "critical density" for these estimates.

The JSC Review states that "The author also states that 'If Air Force predictions are used for launch and explosion rates, the debris never gets to a level where cascading can take place.'"

Space Debris Hazard observes that in the last decades, the global launch rate has decreased by almost a factor of two,¹⁷ much due to CIS for missions that may never be resumed. The Air Force Launch Study predicts no growth in the next few decades;¹⁸ other DoD studies predict a factor of two decrease in the next decade, uncompensated by growth in other sectors.¹⁹ NASA's "Access to Space Study" projects no growth through 2030.²⁰

16. D. Kessler, "Collisional Cascading: The Limits of Population Growth in Low Earth Orbit," *Adv. Space Res.*, Vol. 11, 1991, p. (12)63.

17. "Total Number of Launches per Year," AFSPC, July 1996.

18. "Space Launch Modernization Study ('Moorman Study')"

19. M. Goodney, "Launch Study," Aerospace Corp., 21 Feb 1966.

20. A. Aldrich, AA Office of Space Systems Development, NASA Headquarters, "NASA's Access to Space Study," 5 January 1994.

Moreover, about 50% of U.S. launches are now to deep space, and that fraction is growing linearly with time.²¹ There are technical and economic reasons for other countries to follow the U.S. and CIS in this trend. The main uncertainty in LEO is communication constellations, but a 70 satellite IRIDIUM constellation, launched 4 satellites per rocket on JSC's 10 year replacement times, would require only ≈ 2 additional launches per year, which is small compared to possible growth assumed in the projections above. Thus, published documents do not agree with JSC's projections of continued growth.

Review's Fig. 1 shows that the debris, which was addressed by JSC's previous policy and embedded current national policy, ceased to grow about two decades ago—before those policies went into effect. The total number of objects has not increased in over a decade. The number of intact objects has grown at about $3,500 / 35 \text{ years} \approx 100 \text{ objects/year}$, which is about half the growth assumed in JSC calculations.²² Review's Fig. 2 shows the mass in LEO has increased about $1,800 \text{ ton} / 35 \text{ years} \approx 50 \text{ tons/year}$, although the trend was interrupted in about 1985, and the total has only grown about 1%/year in the last decade. Much of the mass from the peak launch rate should reenter in the next few decades.

The Review states "While the population of small debris has declined in recent years, this is not relevant to the rate of catastrophic collisions."

Space Debris Hazard notes that in JSC's model, an object as small as 6 kg can completely fragment a 6 ton object. The flux of objects larger than 6 kg is an order of magnitude larger than the flux of objects larger than 6 tons, so collisions of small catalog debris objects with large objects is a significant fragmentation mechanism. Thus, this statement is either garbled, reflects a misunderstanding of the workings of JSC's model, or indicates a significant disagreement. Which of these explanations applies should be determined before JSC attempts to produce estimates of growth.

In *Summary*, it is useful for JSC to state that "the population of small debris...is not relevant to the rate of catastrophic collisions"—even if it is true for a reason other than the one intended, i.e., that fragments and operational debris have not grown for decades. Given that they are no longer regarded as a problem, JSC's preferred policy appears to be "limiting the accumulation of mass in orbit." Given JSC's insistence on large, historical launch rates, this policy amounts to the immediate imposition of a policy of de- or re-orbiting satellites and rocket bodies at all altitudes. Before such a policy is imposed, it would be appropriate to resolve the major issues discussed above.

21. TRW Space Log, 1996.

22. R. Reynolds and P. Eichler, "Future Debris Environments Using the Evolve and Chain Programs," op. cit., Fig. 1, "Exponential increase of the population."