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衛星設計を目的とした微小デブリの 2 重壁への衝突過程の数値解析による貫通限界曲線の推定

An Estimation of the Ballistic Limit Curves by Performing Numerical Analyses of the Small-Size Space Debris Impacts on the Components of Satellites for the Purpose of their Designs

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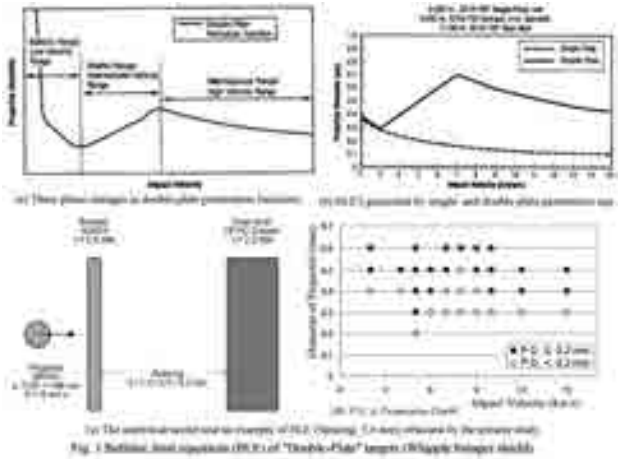
1991 年、NASA/MSFC の K.B.Hayashida らは、1960 年代にアポロ計画を中心にして検討されたメテオロイド防護技術としての 2 重板シールドシステム、いわゆる、Whipple バンパーシールドの貫通限界式、及びその後スペースデブリの脅威を踏まえて見直された式について概観した報告書を出している。そこで検討された式は、膨大な数の 2 段式軽ガス銃を中心とした試験結果に基づいたものであるが、1947 年に F. L. Whipple が提案したアイデアを物理的に精査しメカニズムを明らかにすることによって、その防護システムの有効性を確認したものである。Fig.1(a)は同報告書に記載された、Ballistic, Shattering, Hypervelocity の 3 つの Regime の存在を示した図であり、Fig.1 (b)はこの 3 つの領域の存在のために、1 枚板の貫通限界式に比べて 2 重板シールドシステムの防護性能が如何に向上するかを示した図である。筆者らは、JAXA 宇宙機設計標準推進委員会デブリ防護設計 WG の活動の一環として、「スペースデブリ防護設計マニュアル」の作成を行っているが、その過程で、衛星設計に資するため、実験によるのではなく、数値解析によって貫通限界式の検討を行った。その一例を Fig.1(c)に示す。数値解析のみによって気化領域を含む Whipple シールドの貫通限界曲線(式)の推定を行ったのは世界的に見ても初めての試みであると思われる。

In 1991, K. B. Hayashida et al. at MSFC/NASA published a report reviewing the ballistic limit equations (BLE's)for the “Double-Plate”, so-called Whipple bumper shield, which was investigated as a protection technology for the space vehicle from interplanetary meteoroid impacts mainly for the purpose of the Apollo program in 1960's. The report also reviews the modified equations applicable for the space debris impact, after the space debris problem emerged in 1970's. The BLE's referred to in the report were derived on the basis of vast amounts of hypervelocity impact tests using launchers like two-stage light gas gun, it was confirmed and proven that the Whipple bumper shield is indeed effective for the meteoroid protection by investigating and clarifying the mechanism of it, of which idea was proposed by F. L. Whipple in 1947. Figure 1(a) depicts the existence of three regimes of the ballistic, shattering and hypervelocity, and Fig.1(b) indicates the effectiveness of the “Double-Plate” in comparison to the “Single-Plate”, both graphs are published in the report. The authors have been writing the “Design Manual on Space Debris Protection” as an activity of the Working Group of the Space Debris Protection Design at JAXA, and they tried to derive the ballistic limit curves (equations) of small projectile impacts on the “Double-Sheet” targets only by the numerical analysis, not by the experiment. Figure l(c) shows one of such curves. The derivation of the BLE's for the Whipple bumper shield only by the numerical method, taking into account the shock-induced vaporization, is probably recognized as the first trial in the world.



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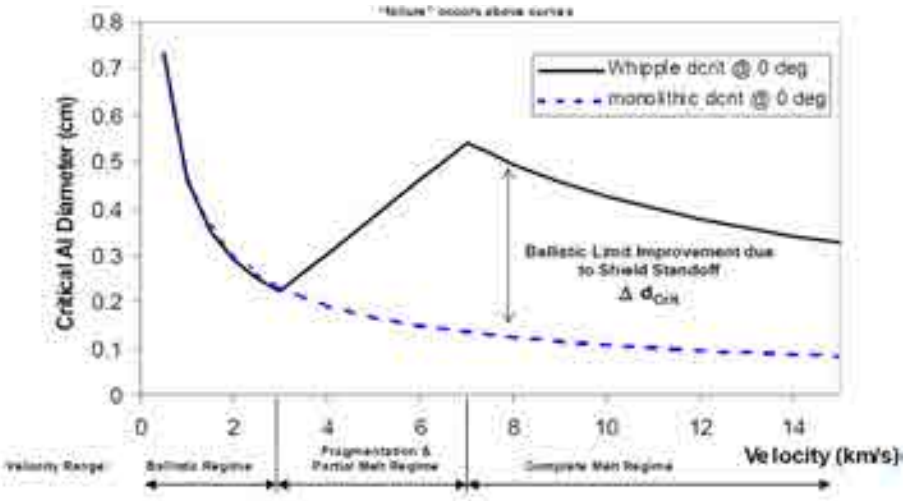
- Ballistic limits for equal mass monolithic target and Whipple shield



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- Ballistic limit curve for the small-size space debris was estimated by the numerical analysis. A hydrocode: ANSYS AUTODYN was applied to the analysis.

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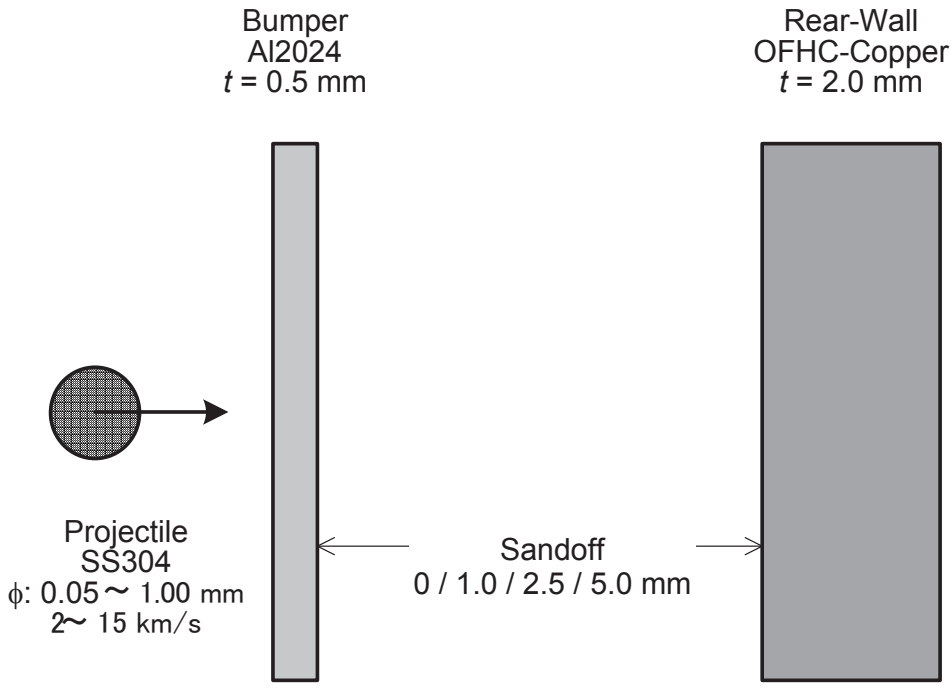
Numerical Analysis Model



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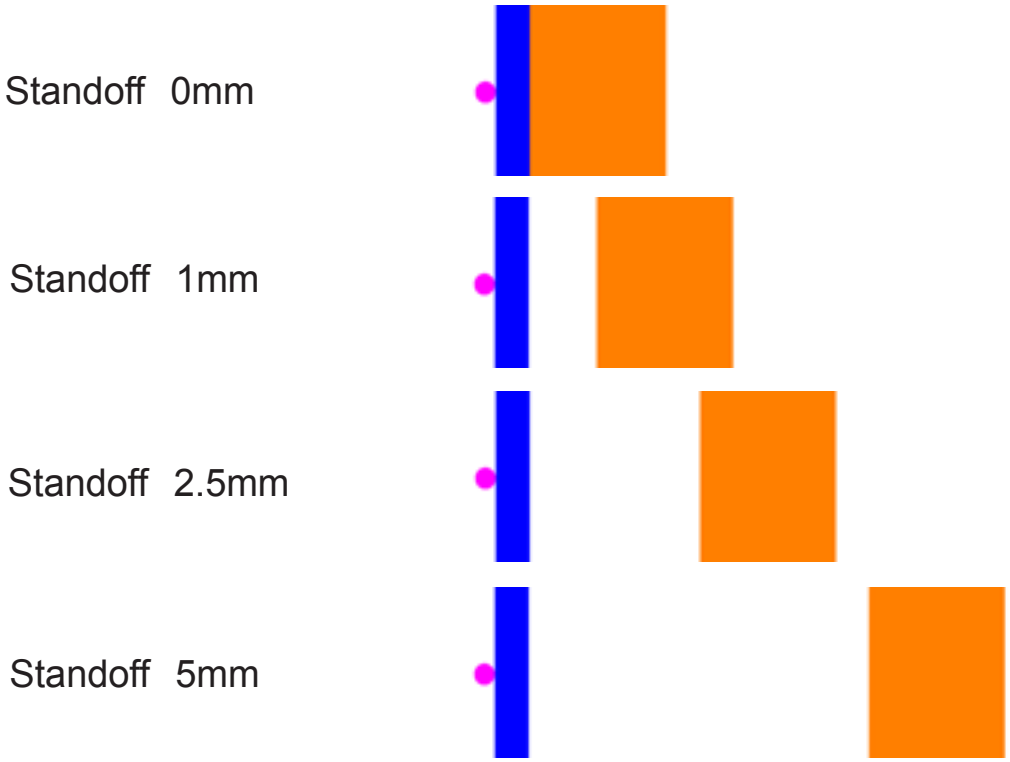
Numerical Analysis Model



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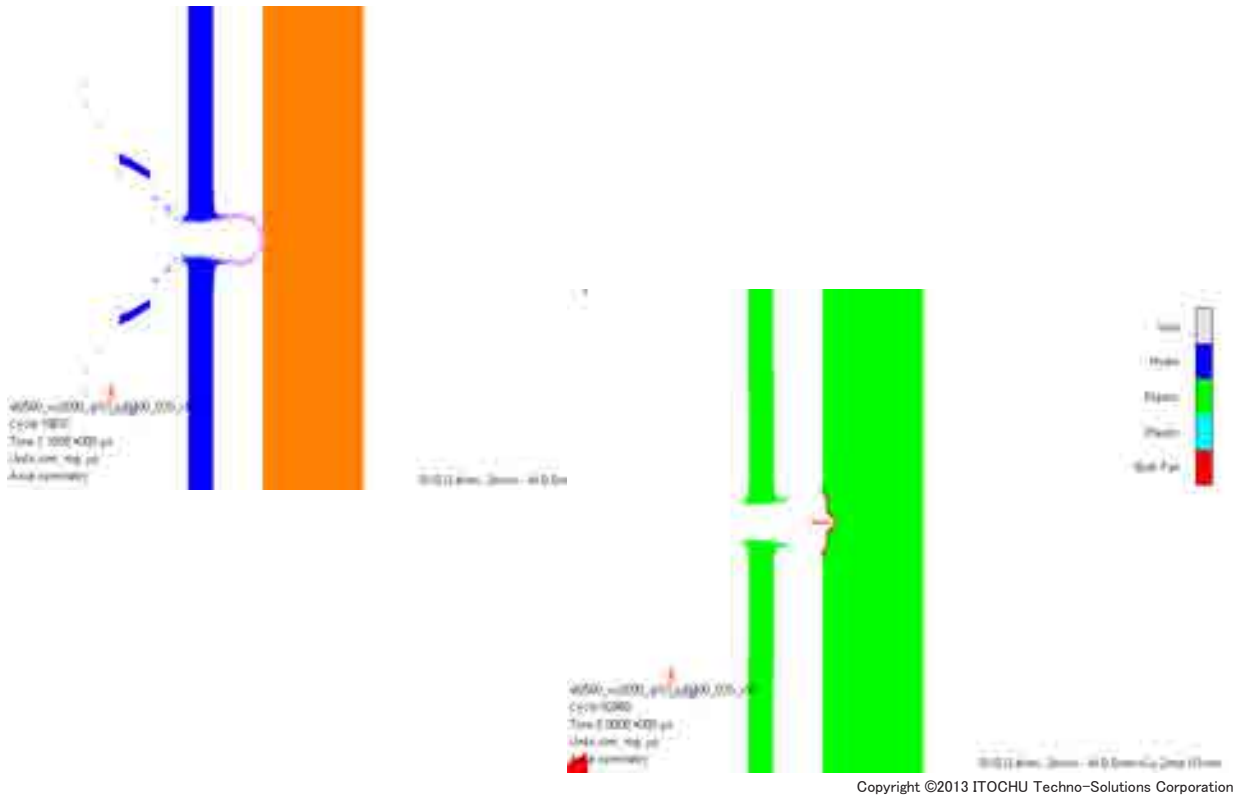
Standoff : 1mm Projectile : φ0.4mm 2km/s



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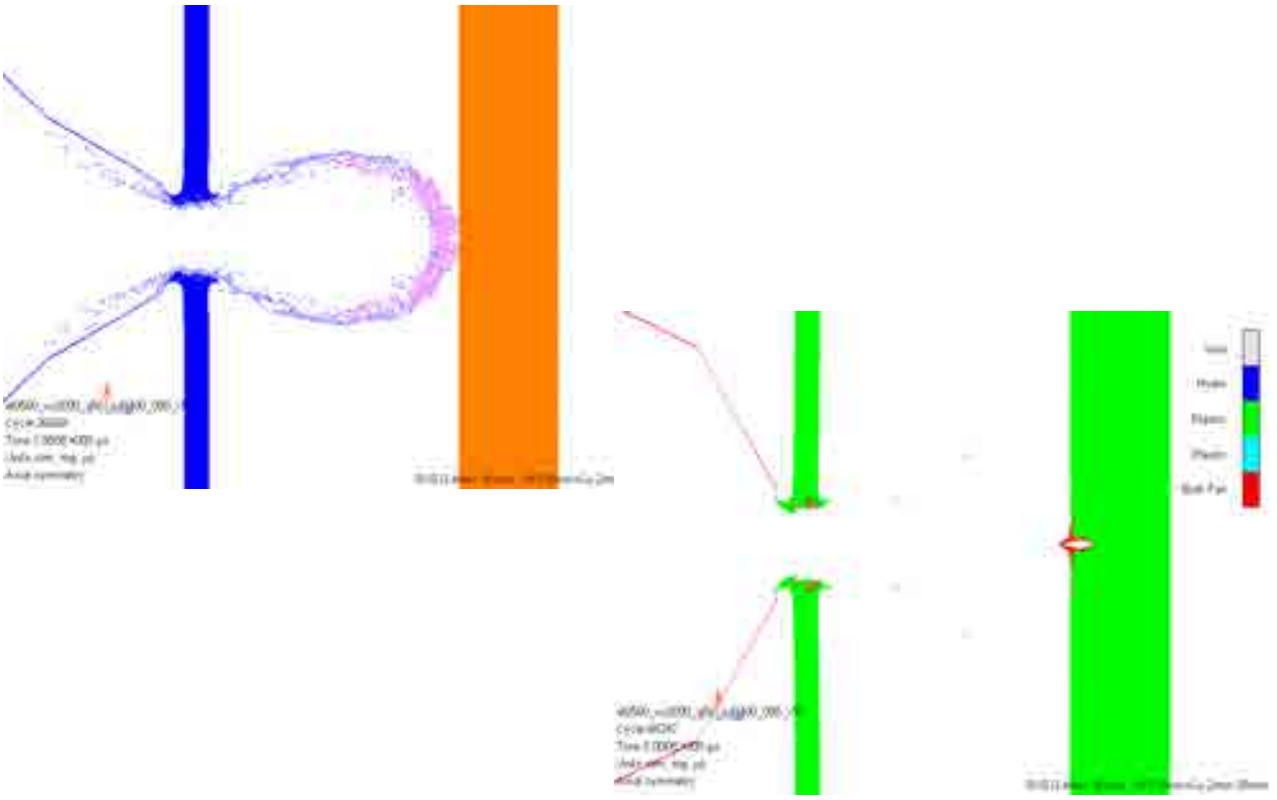
Standoff：5mm　Projectile：φ0.4mm　5km/s



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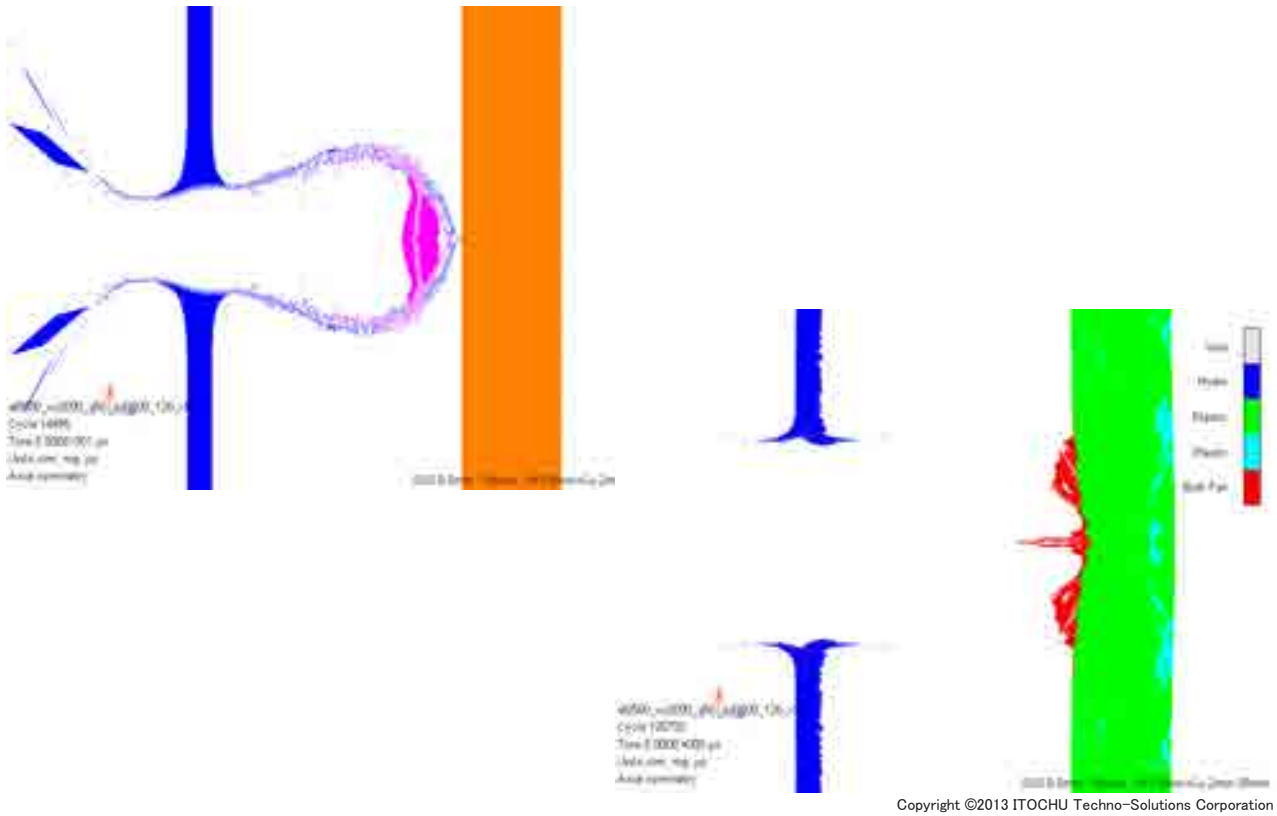
Standoff：5mm　Projectile：φ0.5mm　12km/s



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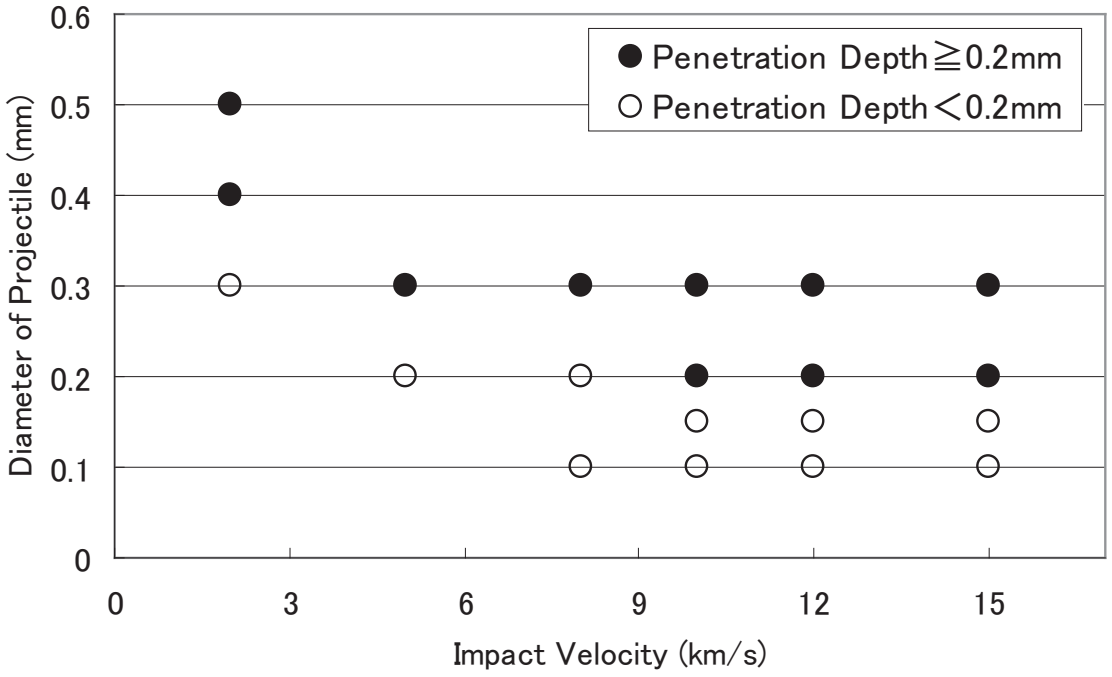
Numerically Estimated Ballistic Limit Curve (Standoff 1mm)



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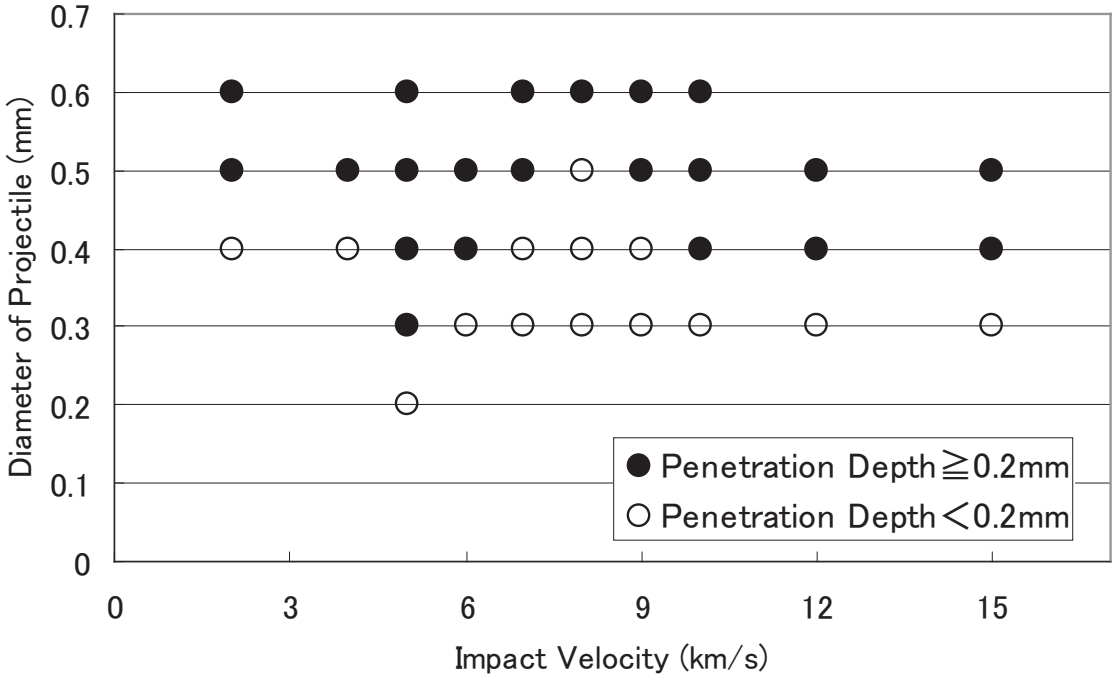
Numerically Estimated Ballistic Limit Curve (Standoff 5mm)



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まとめ、課題

- The authors tried to derive the ballistic limit curves (equations) of small projectile impacts on the “Double-Sheet” targets only by the numerical analysis, not by the experiment. The derivation of the BLE’s for the Whipple bumper shield only by the numerical method, taking into account the shock-induced vaporization, is probably recognized as the first trial in the world.

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