

Orbiter Window Hypervelocity Impact Strength Evaluation
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When the Space Shuttle Orbiter incurs damage on its windowpane during flight from particles traveling at hypervelocity speeds, it produces a distinctive damage that reduces the overall strength of the pane. This damage has the potential to increase the risk associated with a safe return to Earth. Engineers at Boeing and NASA/JSC are called to Mission Control to evaluate the damage and provide an assessment on the risk to the crew. Historically, damages like these were categorized as “accepted risk” associated with manned spaceflight, and as long as the glass was intact, engineers gave a “go ahead” for entry for the Orbiter. Since the Columbia accident, managers have given more scrutiny to these assessments, and this has caused the Orbiter window engineers to capitalize on new methods of assessments for these damages. This presentation will describe the original methodology that was used to assess the damages, and introduce a philosophy new to the Shuttle program for assessing structural damage, reliability/risk-based engineering. The presentation will also present a new, recently adopted method for assessing the damage and providing management with a reasonable assessment on the realities of the risk to the crew and vehicle for return.

Orbiter Window Hypervelocity Impact (HVI) Strength Evaluation

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 - **Dr. James Lankford (Ret), Southwest Research Institute**
 - **Lee Griesemer, Boeing-KSC**

Impacts on Orbit

- **In an inhospitable environment like space, it is inevitable that vehicles will be impacted by micro-particles orbiting at hyper-velocities**
- **When these particles collide with vehicle glass windows, they make damages on the surface that have distinctive morphologies**
- **On the Space Shuttle, these impacts, called hypervelocity impacts (HVI's), are occasionally reported by the crew (when visible)**
- **They can also increase the risk associated with a safe return to Earth**
 - **The window strength is reduced by these damages**

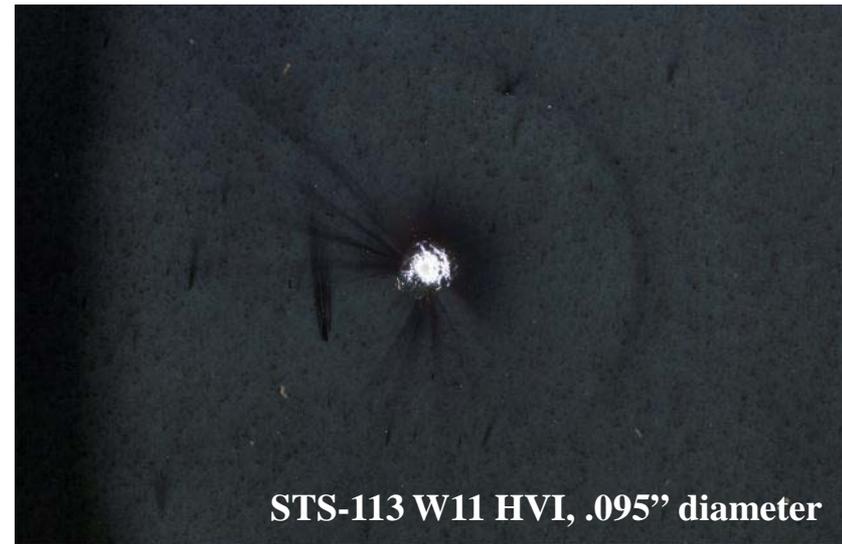


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STS-130 Impact being identified by a crew member

When HVI's are Reported from Orbit

- **A dedicated window team, the window problem resolution team (WPRT), is called during missions to assess the flight risk**
- **Historically, HVI were considered “accepted risk” as long as the pane was intact (no hole)**
- **After the loss of Columbia**
 - **Engineers were required to analytically assess each damage**



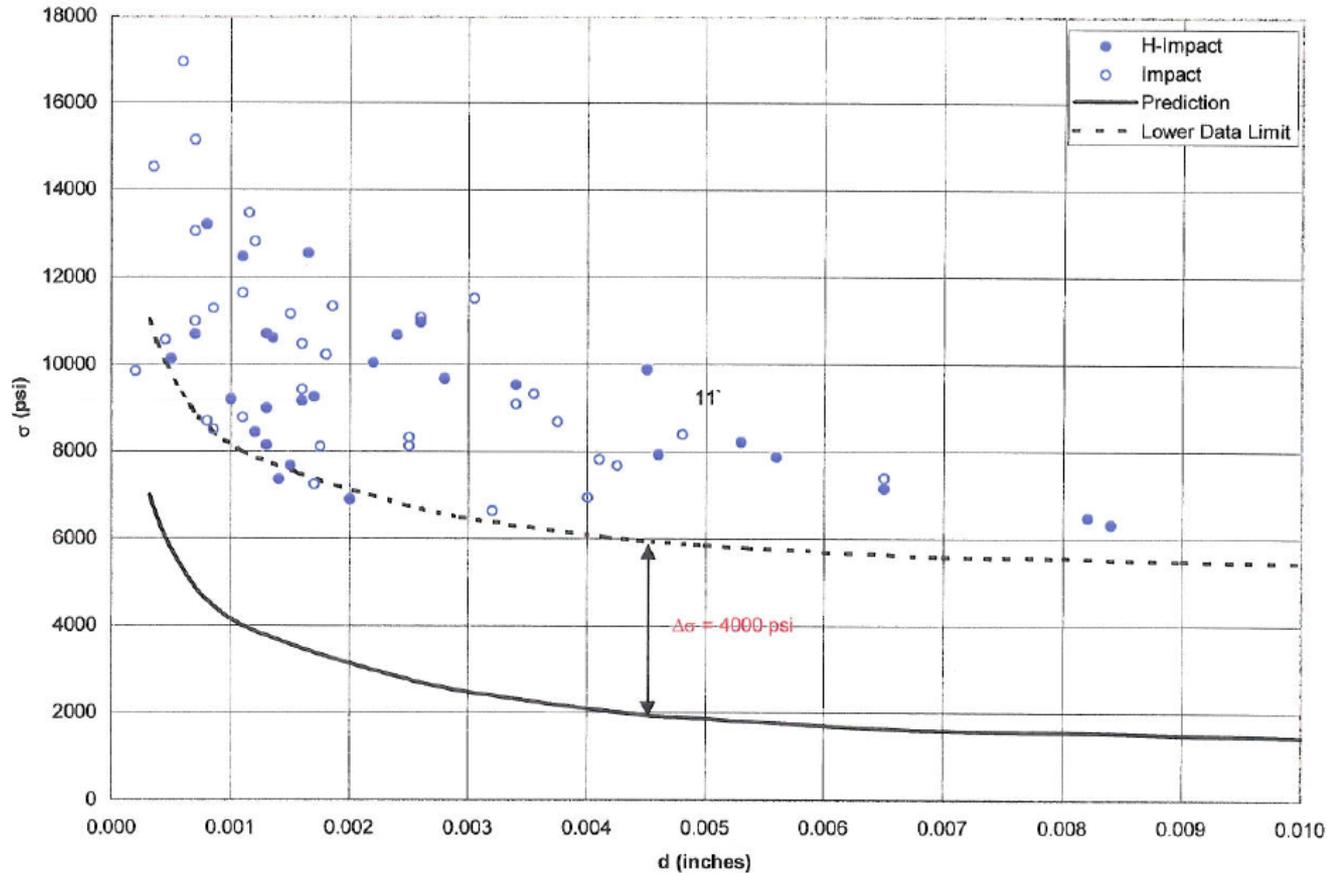
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Traditional Analysis does not Work

- **Analytical assessments were not recommended by engineers due to**
 - **Fracture/Static Fatigue analysis**
 - **Large uncertainty in method**
 - **Reliance on clear crew observation**
 - **Requirement for highly accurate information on damage depth (which is unobtainable by the crew)**
 - **Diameter to depth size assumptions required (conservative)**
 - **Assumptions designed to envelope the inevitable scatter in residual strength are incorporated, including**
 - **fracture properties,**
 - **flaw depth assumptions, and**
 - **loads assumptions**



Assumption Envelope for HVI is Conservative

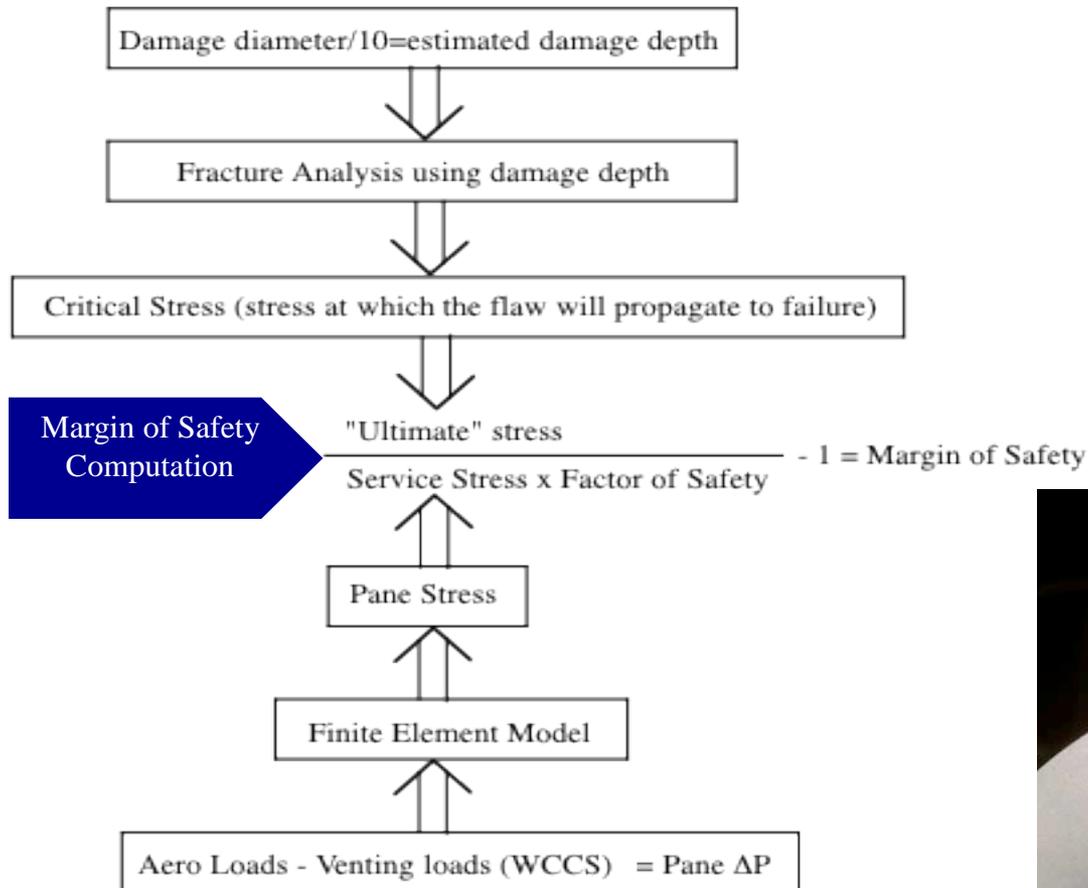


Fracture Analysis of HVI Reported from Orbit

- Often resulted in (falsely) negative margins for entry (increase in risk)
- One solution approach was to reduce the estimates of the flight loads on the windowpanes
 - A flight “trajectory consistent” analysis approach of the window pressures reduced the loads
 - This approach did not work during STS-126 (Nov 2008)



Inputs to Fracture Analysis



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New Approach Alleviates Anxiety over HVI On Orbit

- **Uses HVI residual strength data empirically established in 2000, 2007, and 2009**
- **Uses Risk-based statistics (Weibull) to predict probability of no failure**
- **Recognized a bimodal failure behavior between small and large HVI**
 - **Eliminates all uncertainty due to material property assumptions and damage size, and bases prediction on a statistical evaluation of residual strength for a population similar in size and type of damage**

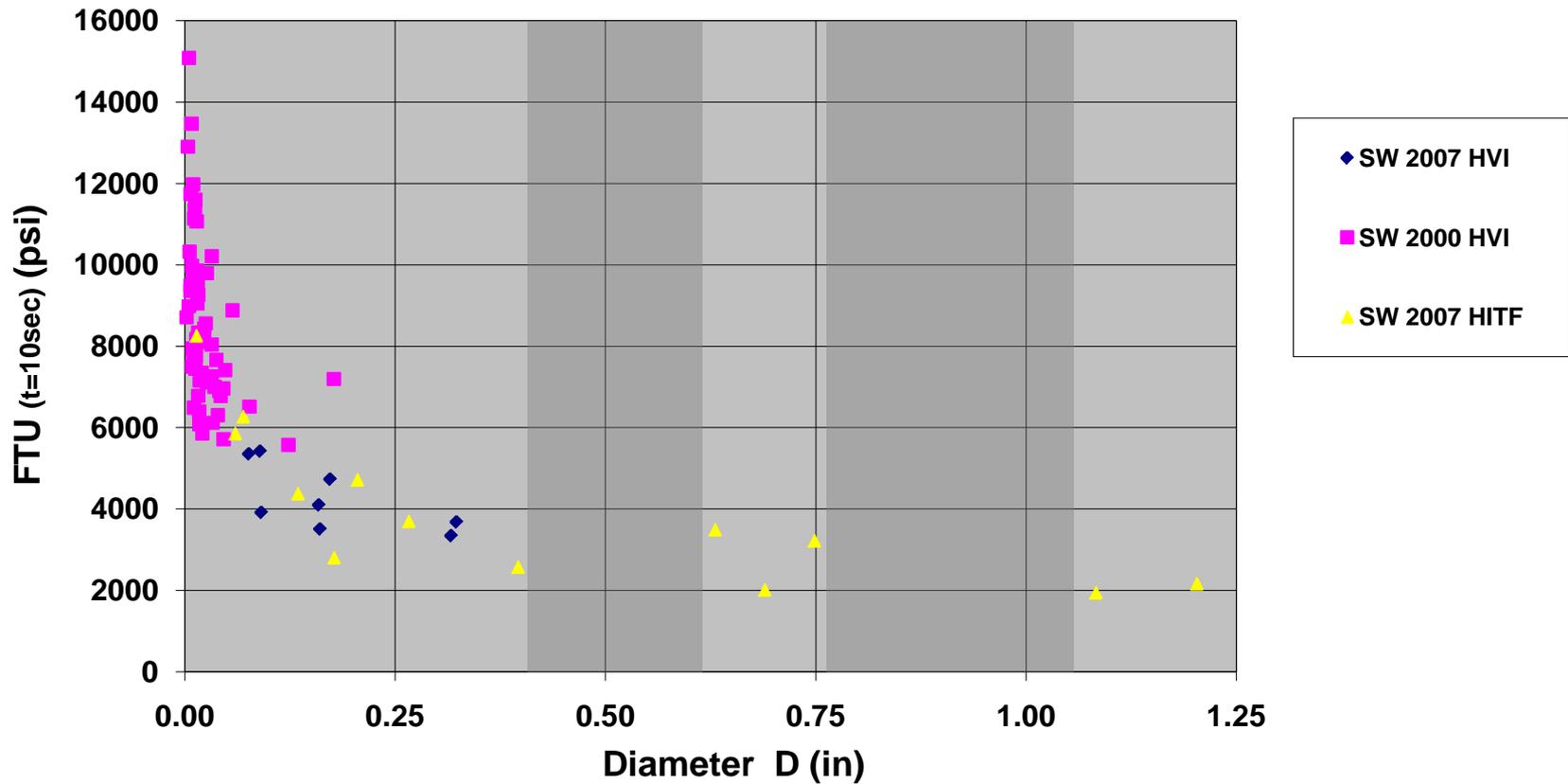


How was this Methodology Established?

- **Natural HVI specimens of a wide variety of sizes (depths & diameters) were cored from retired Orbiter windows**
- **Some specimens were Lab created at WSTF in order to populate the larger size ranges of HVI (very few natural HVI have occurred above .25” in dia)**
- **Data collected in three separate studies in 2000, 2007, 2009**
- **Specimens were carefully and consistently strength tested at SwRI**
 - **ASTM-C-1499-04**
 - **Biaxial stress (ring-ring) test area**
 - **All specimens were tested at the same facility, using same personnel**

2000/2007 Data Gaps

SW 2000/2007 HVI FTU vs Diameter

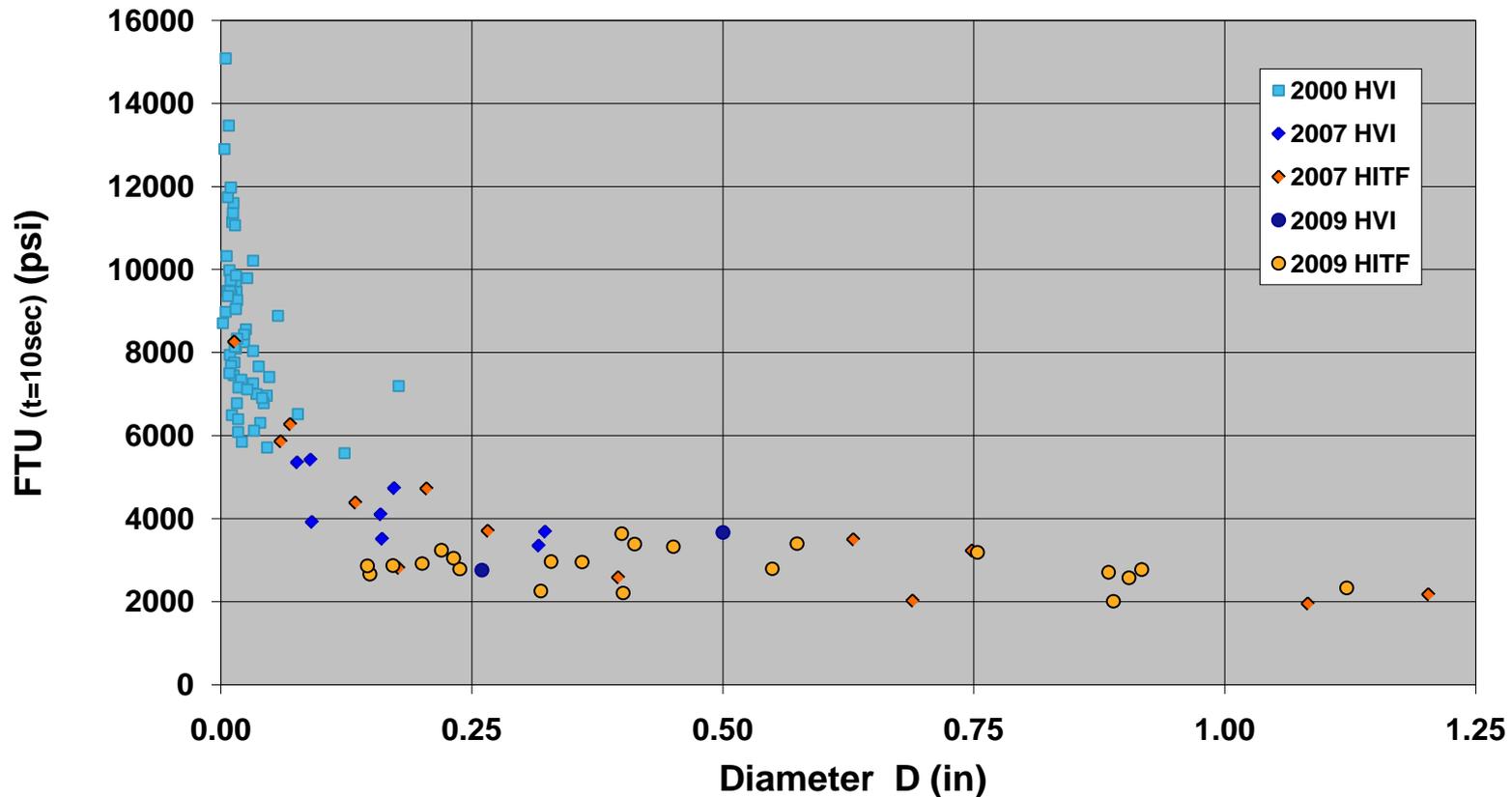


Weibull Technical Evaluation

- **Times of failures and residual strengths were adjusted/normalized to 10 second values**
 - **Data was evaluated to determine if Lab HVI behaved similarly to Natural HVI**
 - **Favorable outcome**
 - **Data was pooled together**
 - **Robustness of testing methodology was evident**
 - **3 distinct studies including natural and lab HVIs**
 - **Data obtained over the course of a decade**
 - **Seamlessly integrated into one smooth trend**
 - **Followed the fracture theory trendline**
-

2009 Data Populates Gaps with Lab HVI

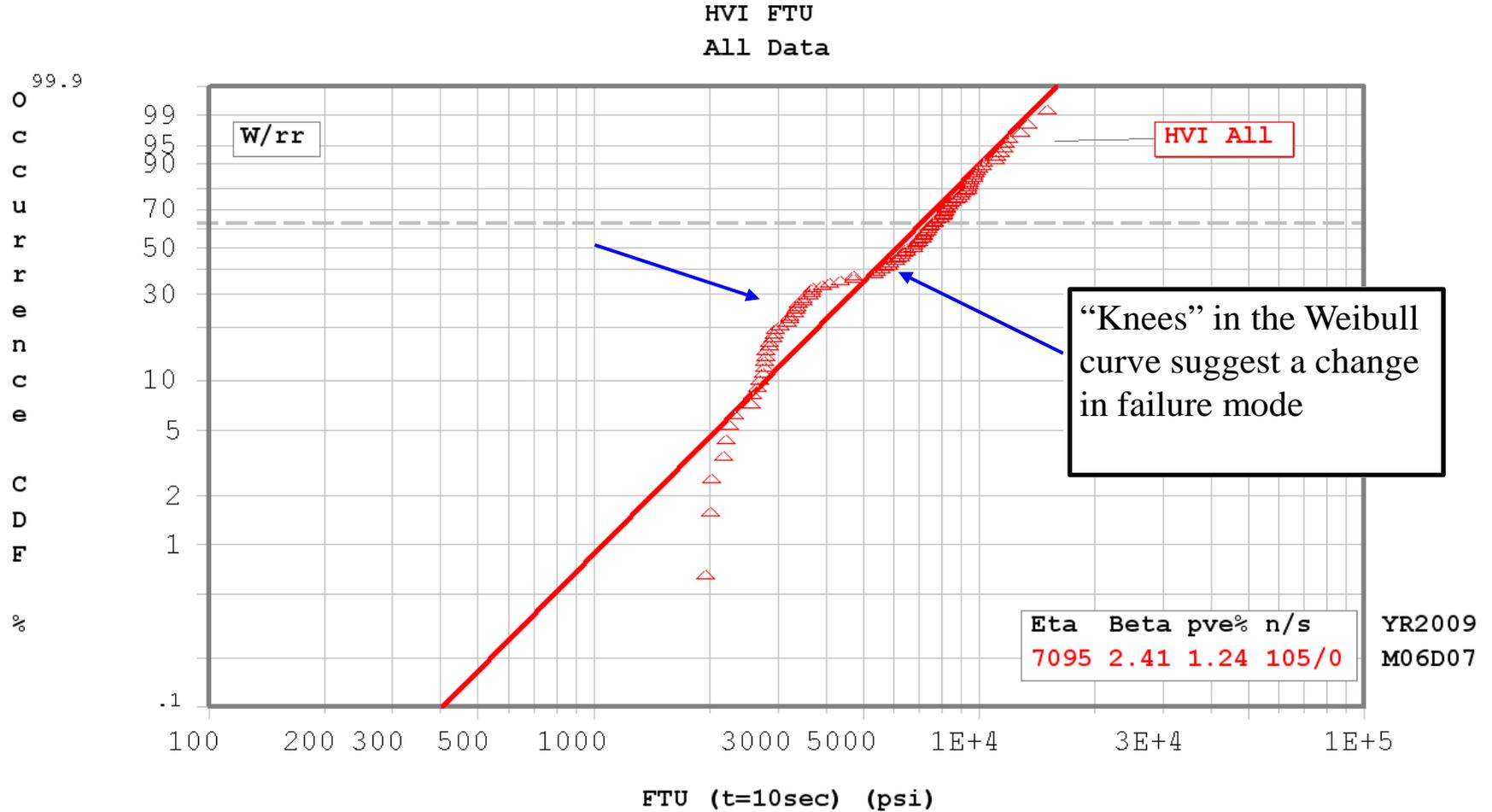
2000/2007/2009 HVI FTU vs Diameter



Use of Weibull as a Flight Tool

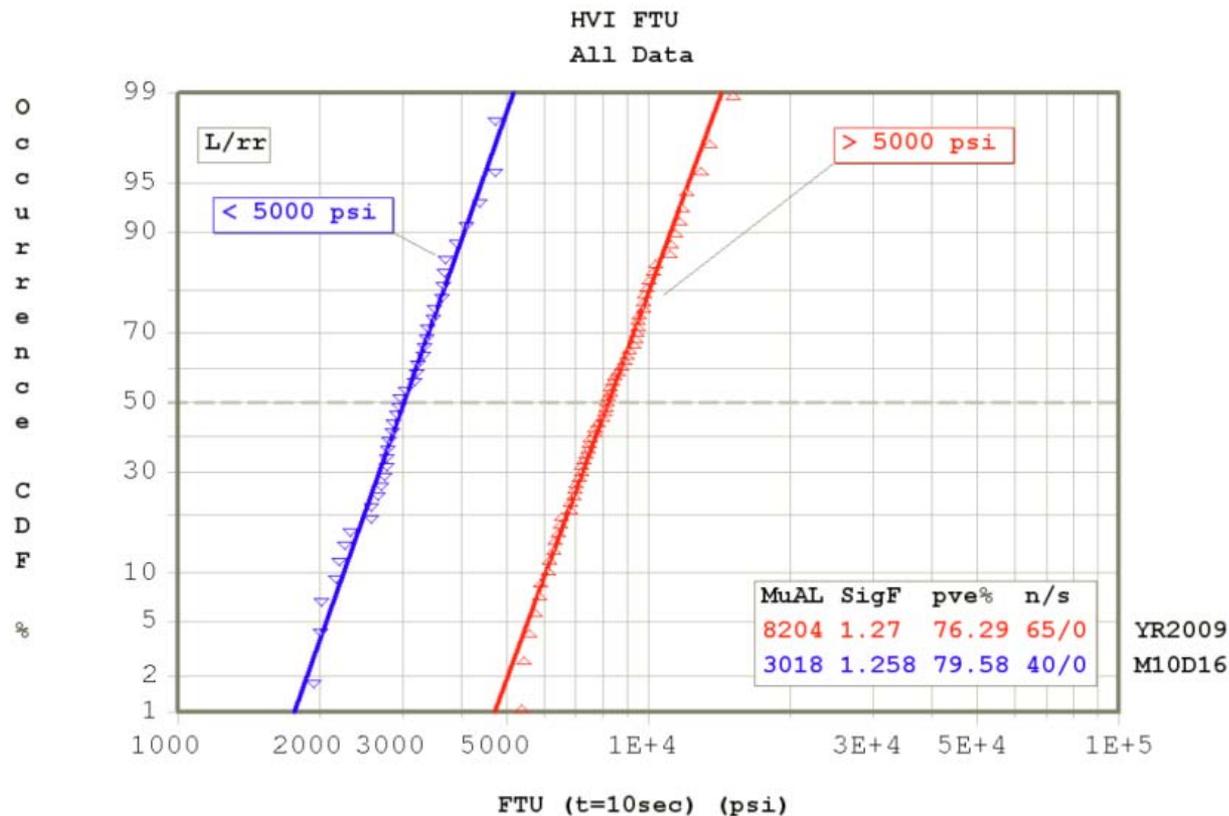
- **Weibull based study conducted by Boeing**
- **Outcome was two predictive Weibull curves**
 - **One group represented small HVI with strengths above 5000psi**
 - **One group represented large HVI with strengths below 5000psi**

All Combined Data Weibull

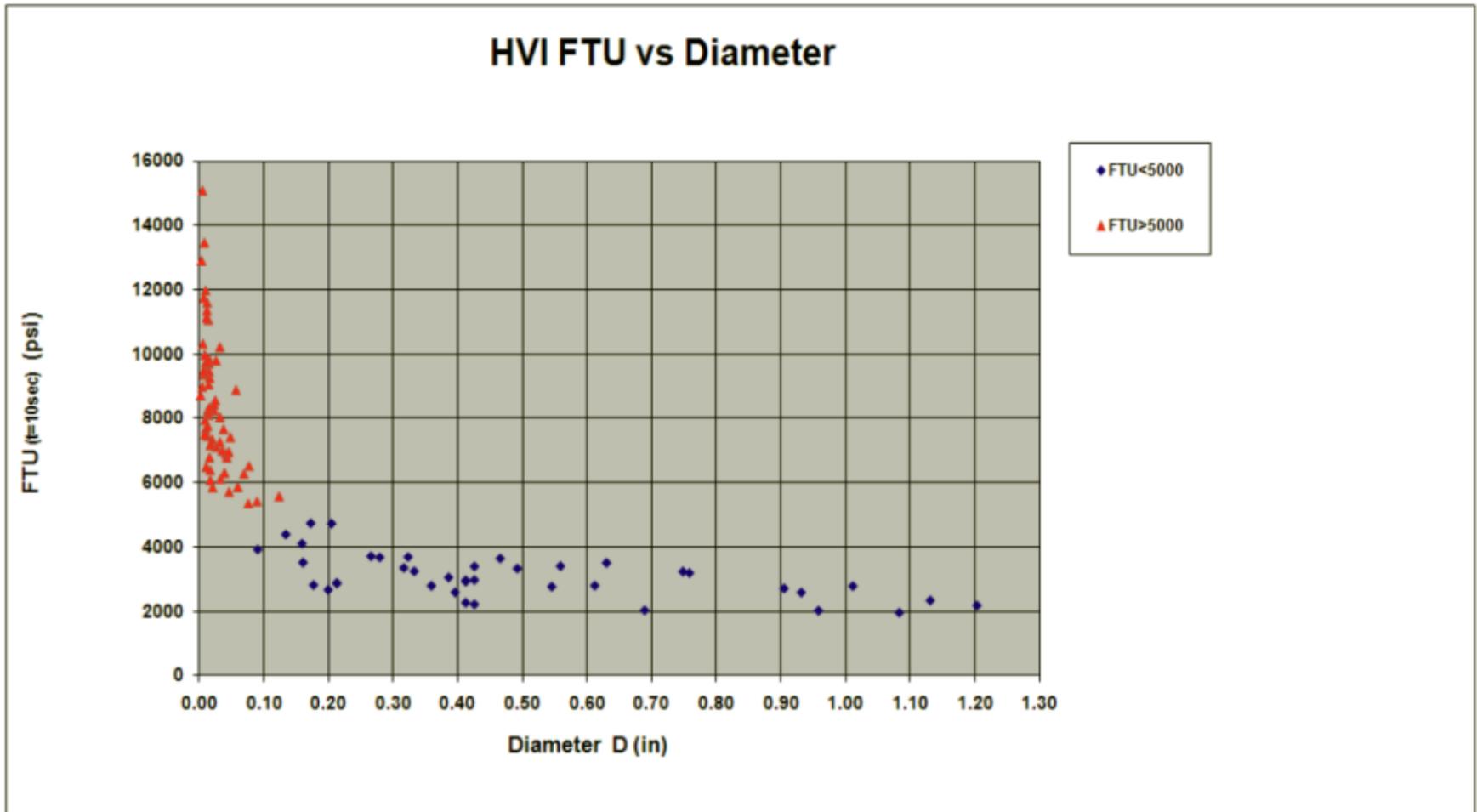


Data Split and Re-evaluated

- A data split at a strength of 5000 psi was determined to provide the best statistical results
- Lognormal distribution was determined to have the best goodness of fit

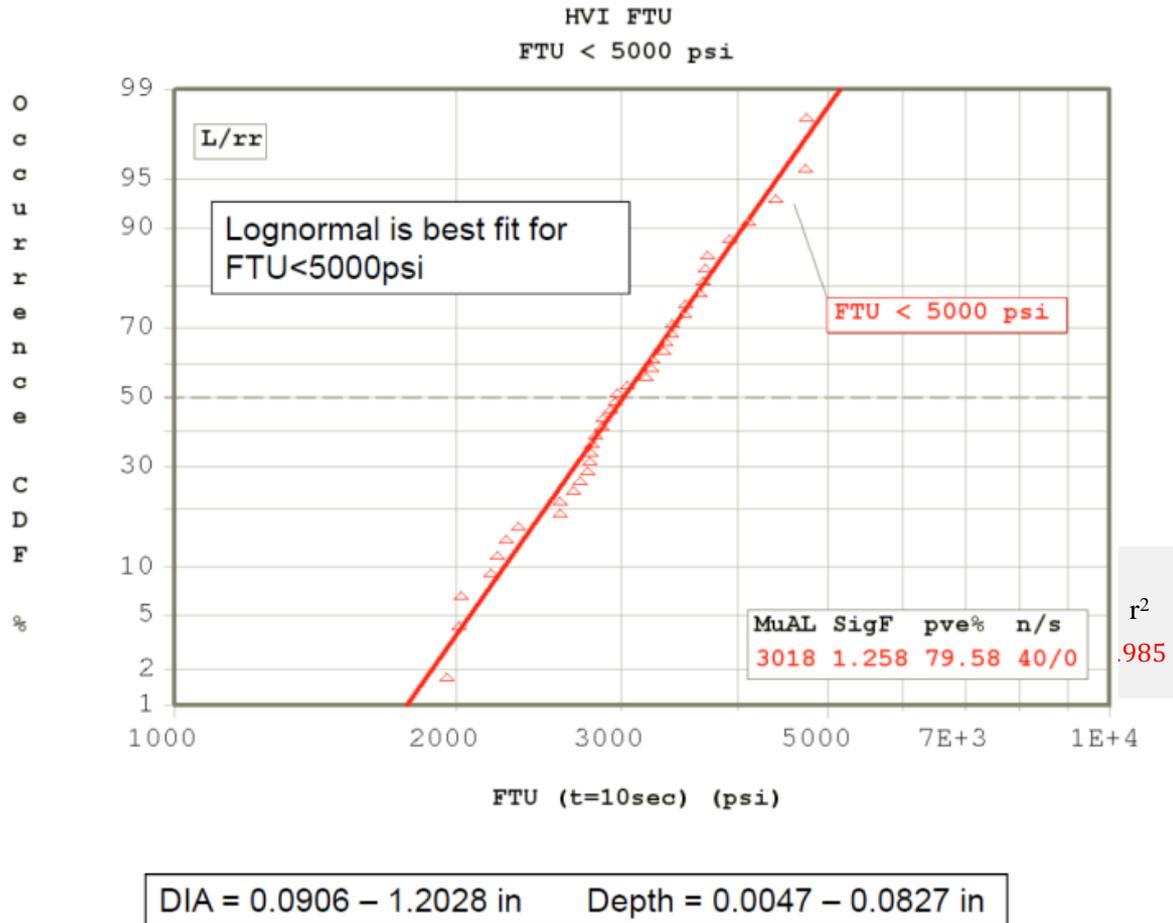


5000 psi Data Split



Window Team uses the Conservative Prediction

- The <5000 psi strength curve can be used for all observed on orbit HVI
- Will be conservative for small damages
 - This conservatism can be addressed according to the team's confidence in the reported data



End Product was a Useful Real-time Tool

- **Orbiter Window Engineers developed a “go/no-go” table to assist mission managers in evaluating what the risks were for a particular size flaw on a particular window during vehicle entry**
- **Tool is risk-based**
 - **No more negative margins**
 - **Increases in risk are quantified**
 - **Realistic conservatism incorporated**

Window	Allowable Diameter
Forward	<1.2”
Middle	<1.2”
Side	<.49”
Overhead	<.49”
Side Hatch	Forward work



Conclusions

Risk based statistical evaluation of a well characterized set of HVI strength data can be used to safely evaluate damages to Orbiter windows during flight.

Thanks

- **I wish to thank Jon Salem for his invitation to present this data in this forum.**
- **I wish to thank the hard working window engineering team members, Lee Griesemer and Orlando Torres, for helping to make this effort possible.**

Questions?
