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Application of CEV Sizing Process of PICA to Stardust and MSL

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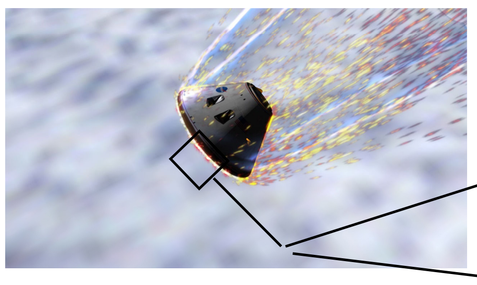
CONTEXT & OBJECTIVE

Orion capsule



Artist view of Orion entry

Orion PICA heat-shield

MSL PICA heat-shield

Example of application

Landed Stardust Recovery Capsule

Recovered Stardust PICA heat-shield

TARGET MISSIONS: CEV, MSL, small probe missions

STARDUST

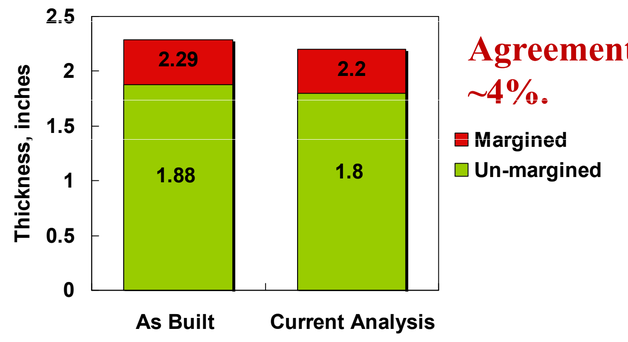
- ✓ Compare the Stardust Heat Shield Design Process with current CEV best practices
- ➢ Validate CEV design process against flight
  - ➢ Overall thickness
  - ➢ Bondline temperature
  - ➢ Recession
- ➢ Assess conservativeness of CEV design
- ➢ Potentially make recommendations to improve CEV design process that could result in mass savings

VERIFICATION

STARDUST DESIGN AND MARGINS

A. UNMARGINED TPS thickness estimate

- One FIAT run using pre-flight PICA model (Stardust model)
- Aerothermal Environments: Design trajectory (ballistic coefficient=70)
- Trajectory Duration: 750 seconds of trajectory
- Initial Entry Interface Temperature: -4 °F
- Maximum Bondline Temperature: 482 °F



Agreement ~4%.

B. Margins applied to thickness

1. RSS of components = 29%
   Trajectory Margin 0%, Aerothermal Margin 21%, PICA Material Margin 20%
2. Machining Uncertainty = 0.01"
3. Ballistic Coefficient of 60 Adjustment = -0.13"

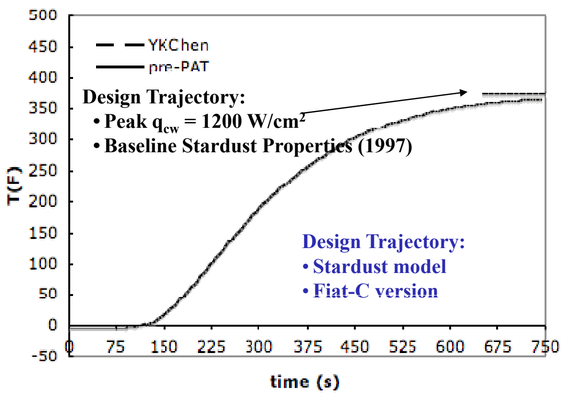
BONDLINE PREDICTION

Flight Heat Shield Design:

- PICA Thickness = 2.29 inches
- TPS Initial Temperature = -20°C=-4F
- Maximum Bondline Temperature = 250°C=482F

Model	750s-Max BLT (F)
YKChen	374
Stardust	365

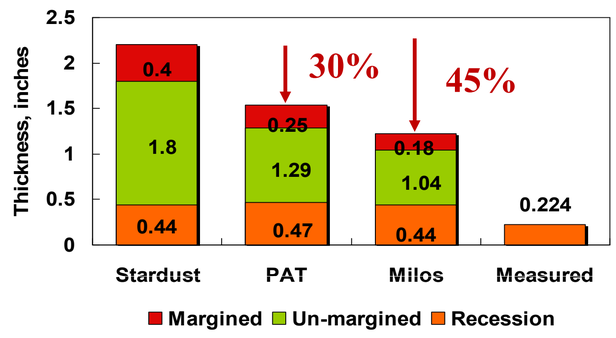
Agreement ~2%.



PICA MATERIAL PROPERTIES

Three separate PICA material property models

1. Stardust (1997): The first PICA model developed for the design of the Stardust heat shield (FIATv1)
2. PAT (2002): Developed by the PICA Analysis Team to correct for model errors in the Stardust model (FIATv2.4)
3. Milos (2007): Developed as part of the Advanced Development Project for the CEV Thermal Protection System (TPS) (FIATv2.4)



Model improvement results in less conservative design

SUMMARY

Agreement within ~2-4% for thickness and BLT:

- Difference in design environments
- Difference in the PICA model
- Using C-FIAT instead of Fortran FIAT

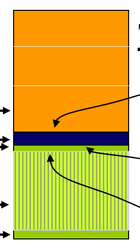
Original design of Stardust heat shield thickness has been reproduced

Verification of original design process and tools achieved

Compared results with three PICA models

MARGINS PROCESS

Thickness	Stardust margin	CEV-margin	MSL-margin
T_1	PICA Milos Design environments NTE-BLT=482 °F Init Temp = -4 °F Fail Lien = 5%	PICA Milos Design environments NTE-BLT=482 °F Init Temp = -4 °F Fail Lien = 5%	PICA Milos Design environments NTE-BLT=482 °F Init Temp = -4 °F Fail Lien = 100%
T_2	T_1*21%	Design environments with aerothermal margin: C_h*1.2 & P*1.05	
T_3	T_1*20%	108 °F	131 °F
Baseline Thickness, T_b	T_1*29%	$T_b = T_1 + \sqrt{\left[(T_2-T_1)^2+(T_3-T_1)^2\right]}$	
Recessed Thickness, ΔT_{Rec}	-	$\Delta T_{Rec} = (\kappa-1)\left(R_1+\sqrt{(R_2-R_1)^2+(R_3-R_1)^2}\right)$	
Final Thickness	T_1*29%+0.01"-0.13"	Max(1.1xT_b, $T_b + \Delta T_{Rec}$)	



Material	Temperature Constraints
PICA	600°F Max (was 482°F in Stardust)
HT-424 (0.055")	
Carbon FS composite (0.02")	350 °F Max (additional constraint)
Al-5056 HC Core (0.5")	250 °F Max (additional constraint)
Carbon FS composite (0.02")	

COMPARISON

Stardust PICA model&margins → PICA Milos Model w Stardust margins → PICA Milos Model+CEV margins → ALL CEV trades → PICA Milos Model +MSL margins

Case	Stardust-Original design	Stardust	CEV-margin	Stardust sizing with all CEV trades	MSL-margin
Trajectory Dispersed	1.88	1.04	1.04	1.52	1.17
Aerothermal Margined	2.27	1.26	1.11	1.55	1.40
Thermal Margined (Material Properties)	2.26	1.25	1.21	2.17	1.33
Baseline Thickness, T_b	2.43	1.34	1.23	2.17	1.45
Recessed Thickness, ΔT_{Rec}	-	-	0.17	0.17	0.32
1.1 x T_b	-	-	1.35	2.39	1.59
$T_b + \Delta T_{R\text{-}margin}$	-	-	1.39	2.34	1.77
Final Thickness	2.29	1.22	1.39	2.39	1.77
Margined-Unmargined	0.41	0.18	0.35	0.87	0.60

0.19 0.65 0.28

CONCLUSION & OUTLOOK

1. PICA material properties (Stardust to Milos): 45% reduction in HS thickness
2. Recession is overpredicted by ~50% in all the models
3. Not to Exceed Bondline Temperature Material Performance: 12% reduction in HS thickness
4. Multiple Temperature Constraints: 38% increase in HS thickness

1. CEV Margin Policy: increase of 14% in HS thickness
   - Less conservative (45%) in terms of PICA material properties
   - More conservative (58% to x2) in terms of applied margins
2. MSL Margin Policy: increase of 45% in HS thickness
3. The Margined-Unmargined difference has become larger by ~2 in CEV and ~3 in MSL