MODELING OF HEAT TRANSFER AND ABLATION OF REFRACTORY MATERIAL DUE TO ROCKET PLUME IMPINGEMENT

Michael F. Harris

Team QinetiQ-ESC-Sierra Lobo Inc. Kennedy Space Center, FL

Bruce T. Vu

NASA Kennedy Space Center, FL

ABSTRACT

CR Tech's Thermal Desktop-SINDA/FLUINT software was used in the thermal analysis of a flame deflector design for Launch Complex 39B at Kennedy Space Center, Florida. The analysis of the flame deflector takes into account heat transfer due to plume impingement from expected vehicles to be launched at KSC. The heat flux from the plume was computed using computational fluid dynamics provided by Ames Research Center in Moffet Field, California. The results from the CFD solutions were mapped onto a 3-D Thermal Desktop model of the flame deflector using the boundary condition mapping capabilities in Thermal Desktop. The ablation subroutine in SINDA/FLUINT was then used to model the ablation of the refractory material.

INTRODUCTION

Under the launch induced environment investigations currently in work at Kennedy Space Center to meet the needs for SLS and other vehicles, a thermal analysis of the flame deflector was needed to predict the amount of refractory material loss due to rocket plume impingement. In the past, the analysis was performed using THERM1D which is onedimensional ablation analysis software where the analysis is limited to a specific location as opposed to the ablation analysis being performed for the entire surface. An example result of THERM1D analysis indicating surface thickness with respect to time is shown in Figure 1.



Figure . Example of THERM1D Output.

Although this software has proved to be sufficient in past analyses, by making use of CR Tech's Thermal Desktop software boundary condition mapper and ablation subroutine the onedimensional ablation analysis can be performed for the entire surface providing the analyst with a contour plot of surface thickness. The model can not only show the maximum ablation but also the location at which we can expect the maximum ablation to occur. The boundary condition mapper allows for highly accurate, transient CFD heat flux data which considers the complex compressible fluid dynamics that impinges on the flame deflector to be mapped to the Thermal Desktop geometry. Once the data is mapped, the Thermal Desktop simulation can be executed to give the ablation over the flame deflector surface. The scope of this ablation analysis does not consider charring or pyrolysis of the material. Figure 2 gives an example of the results obtained by Thermal Desktop.



Figure . Thermal Desktop Surface Heat Flux and Surface Ablation Thickness Examples.

Figure 3 shows some of the concepts for the flame deflector which the thermal analysis is performed.



Figure . Flame Deflector Geometries

MODEL SETUP: MESHING

The model setup was started by importing the CAD geometry into NX/NASTRAN and obtaining a surface mesh or solid mesh depending on the analysis. The mesh can then be imported into Thermal Desktop using the import features in the software, as shown in Figure 4.

ASTRAN M	odel Import Options		2
Input File:	\cad models\model1_sir	m1-solution_1.dat	
Import F	E model as a thermal model		
C Import F	E model as graphics only		
Submodel:	MAIN		×
Layer:	0		
Convert	Thermal Boundary Conditio	ns	
F Put Eler	ments on Layer by Physical I	D	
Note: Befor are the sam	e importing a NASTRAN mo e as the NASTRAN model.	idel, please make si	ure that the Thermal Desktop units
	ОК	Cancel	Help

Figure . NASTRAN Model Import Window

Once the analyst imports the mesh, the thermal model should be shown as a AutoCAD[®] drawing. The thermal desktop models for the flame deflector analysis are shown in Figure 5. A 2-D surface mesh or a 3-D solid mesh can be used depending on the analysis.



Figure : Imported NASTRAN mesh into Thermal Desktop

MODEL SETUP: THERMOPHYISICAL PROPERTIES & DEFINING ABLATION NODES

Under the thermophysical property manager, the material properties are specified. To take advantage of the ablation subroutine in Thermal Desktop, the analyst must specify ablation for that material. The thermophysical property menu is shown for the refractory material in Figure 6.

Property:	menactory material				- Sec color
Comment:		Service of the servic			
Conductivity	[W/m/K]			17	
k	0.504798	Edit Table	Use Table	Pressure	Use Pressure
1.9	0.999999	Edit Table.	🗖 Use Table	Pressure	🗖 Use Pressure
kz.	0.399999	Edit Table.,	Use Table	Presoure	Use Pressure
Isotrop	ic				
C Anisot	opic				
Specific Hea	t [J/kg/K]				
ср	1548.2	Edit Table	Use Table	Fusion	Use Fusion
Density * [kg	/m^3]	THE REPORT			
rho	1842.12				
Effective emi	ssivity				
e-star	0	(used for insula	tion and core)		and the second second

Figure . Thermophysical Properties for Refractory Material

The ablation temperature is 1373 K and the Heat of Ablation is 1.67 MJ/kg describing the refractory material for the analysis of the flame deflector.

The ablation nodes then are specified by editing the Thin Shell Data menu for the surface elements. Under the insulation tab, the insulation can be applied to the top/outside surface.

The material can be chosen from the drop down menu and a thickness can be specified. The flame deflector has 6 inches of refractory material thickness. The number of nodes which the thickness must be discretized also must be specified, this left to the analyst to determine.

BOUNDARY CONDITION MAPPER

The next step is to define the boundary conditions before executing the program and performing the analysis. The boundary condition for the flame deflector heat flux is computed by a transient conjugate heat transfer CFD code that is coupled with the highly complex flow of the 4 RS-25/SSME's and 2 solid rocket boosters impinging on the deflector. The boundary condition mapper feature of Thermal Desktop is capable to take the transient surface heat flux data and map it over the Thermal Desktop model surface.

To begin mapping, the analyst must first have the data in the appropriate format defining the data type, either heat flux or surface temperature, the units of the data, the coordinates of the nodes, and nodes that define the elements, specified as either triangles or quadrilaterals. For this analysis, a MATLAB script was developed in order to take the CFD data, usually provided in a TecPlot[®] format by ARC, and proceeds to format the data quickly into the required boundary condition mapper format to be read by Thermal Desktop. An example of the boundary condition mapper file format is shown in Figure 7.

```
TEMPERATURE DEPENDENT HEAT FLUX BCM Sample Input
        Note: Please note that all information including and after the '!'
        is for description and should not be in the actual file.
DATA: TEMPERATURE DEPENDENT HEAT FLUX
UNITS LENGTH meters
UNITS TEMPERATURE R
UNITS TIME SECONDS
UNITS DATA W/cm2
TEMPERATURES 2
300.000000
1000.000000
NODE 1 0. 0. 0.
NODE 2 0. 1. 0.
NODE 3 1. 0. 0.
NODE 4 1. 1. 0.
NODE 5 2. 0. 0.
NODE 6 2. 1. 0.
TRI 1 1 2 3
TRI 2 3 2 4
TRI 3 3 4 5
TRI 4 5 4 6
TIME 87.000000
                ! Flux for node 1 at T = 300
1.01
                ! Flux for node 1 at T = 1000
1.02
                ! Flux for node 2 at T = 300
2.01
2.02
3.01
3.02
4.01
4.02
5.01
5.02
6.01
6.02
TIME 90.000000
11.01
11.02
12.01
12.02
13.01
13.02
14.01
14.02
15.01
15.02
16.01
16.02
```

Figure . Example of BCM File Format

Once the formatted file is created, the file can be used as input to the boundary condition mapper. After the file is read into Thermal Desktop, the BCM will be presented as a mesh ash shown in Figure 8. The remaining mapping procedures are shown in Figures 9-11.



Figure . BCM Mesh Extracted From CFD Model

Using the AutoCAD commands such as align or move, the BCM must be coincident to the thermal model surface to insure an accurate mapping of data.



Figure . Align BCM to Thermal Model

The BCM can be edited to point to the desired thermal model elements the data should be mapped onto and to specify variable tolerances. A sufficient range of tolerances should be given to insure that all the points are successfully mapped. In the case of this analysis, the Apply surface thickness to test points should be deselected. Deselecting this option maps the data using the position of the elements where they are currently positioned in the thermal model as opposed to some thickness relative to the surface mesh.





After completion, the successful mapping of data should shown as in Figure 12.



Figure . Successful Mapping of the Heat Flux Boundary

POSTPROCESSING

The post processing of data in Thermal Desktop can be intuitive to the analyst for displaying heat rate, heat flux and temperature contours. For displaying contours of surface thicknesses, the postprocessing is not as straightforward. After completion of the processor the ablation subroutine outputs a text file. The text file must be imported into the postprocessing datasets. These steps are illustrated in Figures 10-12. The postprocessing datasets window in shown in Figure 10.



Figure . Post-processing Datasets Import Window

The analyst can add new data sets to be used in the post processor showing color contours. By selecting add new and choosing a text transient file, the surface thickness time history text file can be imported into the post processor. The data set source selection window is shown in Figure 11 as well as the drop down menu to select the file.

Postprocessing Datasets	×	Postprocessing Datasets	X
Postanecessing Datasets Current Data Set case() sev Cove() Sec Data Set Source Selection Postprocessing set name Postprocessing set name Data Source C Sinda/Flaint C Radus C Text File C Text File C Text File C Text File C Heating Rates	Add New Sei Curiert Deiste Rename Edit	Postprocessing Datasets Current Data Set second sav select TEXT TRANSIENT input file name Select Data File DK Cencel	Add New Set Current Delete Rename Edit
OK Cencel Heb		Connerk SINDA/FLUINT Sove File: cse0.tev Description: Close Help	-

Figure . Text Transient File Import Window.

Once the file has been chosen, the set transient text dataset properties window will appear. Due to the existence of ablation nodes and for any model using some form of insulation, the selection to plot MLI should be made from the drop down menu. The selection will plot the data that exist on the top or bottom sides depending on the selection made. For the analysis of the flame deflector, the selection plot MLI on top out sides was chosen to capture the ablation nodes on the surface. The window for setting the transient text dataset properties is shown in Figure 12.

rrent Data Set: case0.s	av.		
ase0.sav			Add New
			Set Current
	Set Transient Text Dataset Properties	×	Delete
	Select a Time/Record		Rename
	0 000 0.0134 0.0269 0.0403 0.0538 0.0672 0.0806 0.0941 0.108 ▼ Plet MLI on top	out sides	Edit
	Comment:		
	Transient Text Data File: case0_ablate_thickness.txt Description:		
omment: INDA/FLUINT Save File: ase0.sav escription:	OK Cancel	Help	
	and the second second second		

Figure . Set Transient Text Dataset Properties

RESULTS

Heat Flux Data Mapping Comparison

The heat flux data used in the Thermal Desktop model is extracted from Computational Fluid Dynamic models provided by Ames Research Center. The heat flux data is computed from a conjugate heat transfer model where the maximum temperature is capped at the melting temperature of the refractory material. The melting temperature is approximately 1373 K. The mapping of the heat flux data showing good qualitative comparison between the CFD result and the Thermal Desktop result is shown in Figure 13. The difference in heat flux magnitude is a caused by the difference in area between the elements of the CFD model and the Thermal Desktop model.



Figure . Heat flux data from CFD solution using TecPlot[®] and Mapped data to Thermal Desktop[®] Model.

Surface Thickness Results

From the thermal desktop analysis the analyst can produce results for the mapped heat flux and surface thickness. The base material surface temperature contour can also be produce, but the temperature change of the base material for this analysis was negligible and out of the scope. Figures 17-20 summarizes the results from the analysis.



Figure . Heat Flux and Surface Thickness Contours in result of SLS Vehicle



Figure . Surface Thickness versus Time at the Impingement and Reattachment Regions.



Figure . STS Validation Case



Figure . STS Validation Case Surface Thickness versus Time.

lable	. 5	ummary	ot ot	results

Analysis	Time (sec)	Change in Surface Thickness (in)	Ablation Rate (in/s)
STS Validation	1.344	0.20	0.15
SLS Concept	1.239	0.15	0.12

CONCLUSIONS

The analysis so far has shown the benefits in using CFD and Thermal Desktop tools in tandem by utilizing the boundary condition mapper. The highly transient, highly compressible flow from the rocket plume can be modeled using high fidelity numerical CFD codes. By extracting the thermal data from the CFD models, one can perform thermal analyses that can benefit the determination of insulation required or a thermal structural analysis can be performed to insure minimum stresses. In addition, the knowledge gained using the ablation subroutine gives our analysis group a tool in the future need for an ablation analysis.

The flame deflector results show to be within 20% of the expected 0.25 inch loss measured post-launch of a STS mission. The error is believed to be due to inconsistent times at which the plume impinges on the flame deflector. With the addition of vehicle ascent trajectory, it is believed the results will be within the expected measurement. The new concepts for the flame deflector could benefit the launch environment not only in IOP, acoustics, and vibration, but on a thermal basis allowing for a weaker secondary shock wave to form.

ACKNOWLEDGEMENTS

• ,

.

The authors would like to acknowledge Cetin Kiris and Emre Sozer for their wonderful work on providing heat flux data from their CFD models for this Thermal Desktop analysis. This work was funded by the Mobile Launcher Launch Induced Environment project, Task Order 51.

NOMENCLATURE, ACRONYMS, ABBREVIATIONS

ARC Ames Research Center

BCM Boundary Condition Mapper

CFD Computational Fluid Dynamics

KSC Kennedy Space Center

REFERENCES

SINDA/FLUINT User's Manual

Thermal Destop[®] User's Manual

Other suggestions:

To utilize Greek symbols, please use the Symbol font.

Please number figures and tables independently.

Please number equations if they will be referred to in the text.

TFAWS Passive Thermal Paper Session



Modeling of Heat Transfer and Ablation of Refractory Material Due to Rocket Plume Impingement

Michael F. Harris Bruce T. Vu

Presented By Michael F. Harris

Thermal & Fluids Analysis Workshop TFAWS 2012 August 13-17, 2012 Jet Propulsion Laboratory Pasadena, CA

Introduction



- Launched Induced Environment
 - Acoustics
 - Vibration
 - Thermal
 - Modeling of the plume heat flux and ablation of the refractory material.
 - Many different concepts and vehicles are being considered
 - Atlas V
 - Delta IV
 - Liberty
 - Space Launch System (SLS)
 - SpaceX Falcon Heavy
- An efficient method of performing the Thermal Analysis of the Flame Deflector was needed.

Introduction

- Software tools available
 - THERM1D
 - Thermal Desktop[®]







TFAWS 2012 - August 13-17, 2012

Background



- Therm1D has been sufficient in the past for ablation analysis. The analysis is done at a specifically chosen location.
- Thermal Desktop with SINDA/FLUINT has the capability to perform the same ablation analysis but over the entire surface.
- This will help in rapidly determining locations of highest ablation on the flame deflector

Model Setup: Meshing

- NX/NASTRAN
 - Capability at KSC is used to produce meshes to import into Thermal Desktop
 - 2-D surface mesh using triangle or quad elements
 - 3-D solid mesh using tetrahedral or quadrahedron elements.



2D Surface Mesh



3D Tetrahedral Mesh

Model Setup: Defining Surface Parameters

- Surface Parameters
 - Material
 - Thickness

en Nodes: Based on material property	
Material Thickness(m)	
Mild Steel	
DEFAULT 0	
DEFAULT 0	
aterial Drientation name (aniso FEM only)	
Multiplers: Density: 1 U or X Condt 1	
V or Y Cond.	

- Insulation/MLI
 - Defining ablation nodes

Put on top/	out side P	Stack Manager	Put on bottom/in side P
Top/Out Side	Material/Thickness		Bottom/In Side Material
Material	Fondue Fyre		Material DEFAULT
Thicknes	s: 0.1524 m No	mber Nodes: 10	Thickness 0 m Number Nodes 1
	(aterials (Stack)		C Mutuple Materiale (Stack)
Steck:	DEFAULT		Slack: DEFAULT
Top/Out Side	Node Numbering/Creation		Bottom/In Side Node Numbering/Creation
C Use new	submodel:		C Use new submodel
	MAIN	<u>.</u>	MAIN
Calc Type:	Based On Material Props	2	Calo Type: Based On Material Props
Init Temp:	293.15 K		Init Temp: 233.15 K





- Boundary Condition Mapper (BCM)
 - Temperature Dependent Heat Flux (Node Based)
 - Element Based Temperature
 Dependent Heat Flux
 - Units
 - Node Number and Coordinates
 - Tri or Quad Elements and corresponding Nodes
 - Time and Data for each Node

TEMPERATURE DEPENDENT HEAT FLUX BCM Sample Input

Note: Please note that all information including and after the '!' is for description and should not be in the actual file.

```
DATA: TEMPERATURE DEPENDENT HEAT FLUX
UNITS LENGTH meters
UNITS TEMPERATURE R
UNITS TIME SECONDS
UNITS DATA W/cm2
TEMPERATURES 2
300.000000
1000.000000
NODE 1 0. 0. 0.
NODE 2 0, 1, 0,
NODE 3
          O.
             0.
NODE 4 1. 1.
              n
NODE 5 2. 0. 0.
             Ð.
NODE
TRI 1 1 2 3
TRI 2 3
TRI 3 3 4 5
TRI 4 5 4 6
TIME 87.000000
1.01
               ! Flux for node 1 at T = 300
1.02
                ! Flux for node 1 at T = 1000
2.01
                ! Flux for node 2 at T = 300
2.02
3.01
3.02
4.01
4.02
5.01
5.02
6.01
6.02
TIME 90.000000
11.01
11.02
12.01
12.02
13.01
13.02
14.01
14.02
15.01
15.02
16.01
16.02
```

- Large amounts of data needed to be formatted
- Developed MATLAB routine to format TECPLOT[®] files provided by ARC to Thermal Desktop Boundary Condition Mapper Format

Script reads in ARLI Templot Hiles and Dotrents them in Theomet Dotatop HOR Sile Conwait	2 - 5*23 3 - 51
in Inser ni	2 (2) = 3(1)
less ell	a a - 2.
1 a com a 1820A.	end emoralization = "m".c",s"]:
inwrit = E 3102	i_Flart = 1
1 - 1 - 1 - 1 - 1 - 1 - 1 - 1	j statu v j: element rout = 0/554,
er i = .cl/m prest = hunistrifile manig	tor : + 11778
i.esame - sizest f'murleon_iappend, .dst'i:	a - 12 ability of a simplet abult
<pre>ili = importants(tl.ename); ile num = tile num > 200;</pre>	17 3 5 40
ineii+11 = 1150/11 - 5.307r	1 = 1-1r 1 - 1r
cui la	
WAY - (. WOR) STRONGL PADES. AND INVESTIGAE ORACICARD HER, HER, HER, IN	if severifyi, decontrations i → 1
RUIS LANGER - C'URID LARGER MECHENICAL S'IL	CTER 6.6 Autom
DITE TIME - 1'DELTA TOTE ARCONES');	eller i
witz Dera - 1,02110 DELM #(4).31	1: A_2 A 5 = R(5.2), Ga(A 5.2), 20 / A
un_(f_temps = 1/	3 - 3 - 32
- 1/	are a + 32 ang
- 11	8 + la
ada_comnt = 46703/	A set of the set of th
ble i 4 sode power.	1 + 3 + 12
1 - 1+11	1 + 17
1 = 11	950 (1994) (1994) (1995) (1997
xCO + MIII-Ascellable	1 = 2 * -5
2 - 3 + 22	reddate:
8 * 8 * 1/ 26	<pre>gdot(#,1] = #f1).det+(\$,1]).</pre>
= 17	red
An In a two access events	2 - 7 - 17
at j f se	re h
3 = 11	1.0 E 4 179
end	1 - S. PORTA S E. Adapta
1 = 3 + 12	and
k = 8 + 11	and
	while K <- element doubt
mult t c inde soubl	15 4 3 14
12 3 + 39	$\frac{1}{1} \neq \operatorname{ind}_{\mathcal{F}}$
15.3 + 18	of 4. 5/16/12 links AM Dribbourments and Settington(STO2ACM2.m 4 of 4
ity ; 18 18/12 [1103 AM D31Documents and Settingsim\CFDJBCH2.m 3 :	of 4 S/16/12 links AX Sylbocuments and Settings\m\tT028CM2.m 4 of 4
<pre>it3 + 19</pre>	of 4. <u>5/16/12 11:0: AM DilDocuments and Settingsim\UETV28CM2.m 4 of 4</u> x = underlift ¹¹ conductor = foods arenginese, support
<pre>itj r 18</pre>	6. <u>5/16/12 12:05 AV. 57\Decuments and Settings\m\UT028092.m 4 of 4</u> modelse - took aregions inters.p.ttp receives - 10:05 10:05 11 (0:05)2
<pre>it.j + i2 is/12 iii03 AK bitOcomments and pettingsts\OPDUBOR(.m) is/isserWit.estHt.git = 1 3 - 3 ' i</pre>	<pre>of 4 b/je/J2 lifes AM bilbecumments and Settings\m\ETC/BCMD.m 4 of 4</pre>
<pre>15.3 + 19 15/12 11:03 AK Dribcobments and Settingsim\Cf028CH2.m 3 3 + 11 17 Image(M)3.estif1.3H == 1 3 + 1 + 1 end(M)3.estif1.3H == 1 3 + 1 + 1 end(M)3.estif1.3H == 1 </pre>	<pre></pre>
<pre>it.j + 10 it.j + 11 i</pre>	<pre>status of 4</pre>
<pre>15.3 + 10 15.12 11:03 AK DivDocuments and DettingetsVCPOUBCK2.m 3. 15.12 15.1 100.101.131 -= 1 3.2.1 13</pre>	<pre>** / * * * * * * * * * * * * * * * * *</pre>
<pre>it.j + 10 it.j + 11 i</pre>	<pre>i = ists of 4 S/16/12 11:05 AM Dilboruments and Settings\m\CTO2MCH2.m 4 of 4 s = mademilistic restriction and setting the setting and the setting restriction and the setting the setting restriction</pre>
<pre>ID / ID /</pre>	<pre>cf 4</pre>
<pre>it.j + 12 iii.03 AK bitDocuments and petitingstm\OfDiBCN2.m 3 if laws (0):contributions in the set of the set of</pre>	<pre></pre>
<pre>it.j + 19 it.j + 19 it.j + 19 it.j + 10 i</pre>	<pre>cf 4 //i/i/i/i/i/i/i/i/i/i/i/i/i/i/i/i/i/i</pre>
<pre>it.j = 12 ii.03 AK bitDocuments and pettingstmtofDuBCN2.m 3 if least M01:set11.git == 1 3 - 1 + 1 ii.</pre>	<pre>d</pre>
<pre>it.j + 12 it.03 AX b):Documents and Dettingstm\CFD2BCK2.m 3 set: det f least m();packat(;p): == 1 formine; net formine; rest formine; rest formine; rest formine; rest formine; formine;</pre>	<pre>cf 4</pre>
<pre>it 3 + 19 is/12 iii03 AK bitDocuments and petitingstmtofDiBCN2.m 3</pre>	<pre>d</pre>
<pre>12.3 + 12 14/12 (1103 AM D)\Documents and Devilogrom\CfD2BDCG.m 3 3 = 1: weiger (f lease M(1)) and (f), 3) = 1 for (f lease M(1)) and (f), 3) for (f lease M(1)) and (f), 3) i = 1</pre>	<pre>1 1 101/ 1 1 101/ 05 4 5/10/12 13/04 AM DolDocuments and Bettings\m\UTD28092.m 4 of 4 n = maded10/11 restarts - productive (100 1) 100/03 maded = 100/12 100 100/03 maded10/100 100 100 100/03 maded10/100 100/100 100/03 maded10/100 100/100 100/03 maded10/100 100/100 100/03 maded10/100 100/100 100/03 maded10/100/100/100/100/100/100/100/100/100/</pre>
<pre>it.) + 19 it/12 iii03 AK bitOcomments and pettingstmtofDiBCR2.m 3</pre>	<pre>df 4</pre>
<pre>it.j + 12 it.j + 12 i</pre>	<pre>d</pre>
<pre>15.3 + 13 16/12 11:03 AK b: Obcounents and pettingsts(OFDJBCR2.m 3) 3 = 1; 3 = 1; 3 = 1; 1 = 100 = 1</pre>	<pre>df 4</pre>
<pre>15 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 2</pre>	<pre>////////////////////////////////////</pre>
<pre>15) + 19 16/12 ()(10) AM (b) (Decoments and pettings/s(OFD/BCH2.m)</pre>	<pre>df 4</pre>
<pre>15 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 2</pre>	<pre>////////////////////////////////////</pre>
<pre>15 3 + 12 14/12 11103 AX DistBoogneents and Settingstm\CEDDBONG.m 3 3 + 11 med 17 law (1) (and AT); (m + 1 med) 17 law (1) (and AT); 17 law (1) 18 la</pre>	<pre>df 4</pre>
<pre>15 / 1 2 11:03 AM D:\Decuments and De(tings\m.,.\CFDDECM2.m 3</pre>	<pre>////////////////////////////////////</pre>
<pre>15.3 + 12 14/12 11103 AN DivDocUments and DevilogivesVCFD2BCH2.m 3 3 + 11 well if low e 1 ()</pre>	<pre>df 4</pre>
<pre>15 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 2</pre>	<pre>d d)/ic/l/ list AX Sylbocuments and Settings\\CTU28CB2.m 4 of 4 * - mademil(*** * conductions - ***********************************</pre>
<pre>14 /12 /1103 AM DivDockments and Deviloprom\CFD2BCM2.m 3 14 /12 /1103 AM DivDockments and Deviloprom\CFD2BCM2.m 3 14 /12 /10 /10 /10 /10 /10 /10 /10 /10 /10 /10</pre>	<pre>df 4</pre>
<pre>15 / 1 / 3 15 / 12 / 11 / 03 AM</pre>	<pre>ef 4</pre>
<pre>12 / 1 / 2 / 1 / 2 / 4 / 2 / 4 / 2 / 4 / 2 / 4 / 2 / 4 / 2 / 4 / 2 / 4 / 2 / 4 / 2 / 4 / 2 / 2</pre>	<pre>6f 4</pre>
<pre>15 / 13 15/12 / 1103 AM</pre>	<pre>ef 4</pre>
<pre>15 / 1 / 2 15 / 1</pre>	<pre>sf 4</pre>
<pre>12.3 + 13 13/12 11103 AN _Di\Docgments and Settingstm\CED28002.m _3 3 + 31 34(2) 17.18(3) 3 + 31 34(3) 34(</pre>	<pre>ef 4</pre>
<pre>15 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 1 / 2 / 2</pre>	<pre>sf 4</pre>
<pre>16.3 + 12 11.03 AN DivDocUments and DevilogivesVCDDBCH2.m 3 3 + 11 med (7 low - 1) med (8 low</pre>	<pre>ef 4</pre>
<pre>15 / 1 / 2 / 1 / 10 / AK _ D \ Documents and Pettings\m\CfD2BCD2.m _ 3</pre>	<pre>sf 4</pre>
<pre>14 (12) 1103 AN DivDocUments and DevilogiveVCDDBCH2.m 3 3 (1) 10 (10) (10</pre>	<pre>ef 4</pre>
<pre>15 / 1 / 2 / 1 / 10 / AK _ D \ Documents and Pettings\m\CFD2BCM2.m _ 3</pre>	<pre>sf 4</pre>

TFAWS 2011 – August 15-19, 2011



TFAWS 2012 - August 13-17, 2012

 ARC results are mapped to the Thermal Desktop model as a boundary condition



Successful Mapping of CFD to Thermal Desktop



Ablation Subroutine

- Theory
 - 1-D finite differencing through the thickness of ablative material
 - Once the ablating node is reduced to 50%, the node is converted to a arithmetic node.
 - The node is collapsed and the capacitance and energy is transferred to the next node.



Post Processing

- Ablation subroutine exports a file with the surface thickness time history.
- Post processing Datasets
 - Add New
 - Select Text Transient
 File
 - Find and Select ablation text file



TFAWS 2012 - August 13-17, 2012

Post Processing

- Post processing Datasets
 - Find and Select ablation text file
 - Specify Tolerances
 - Give a range
 - 1e-05, 2e-05, 3e-05.....
 - Select Plot MLI on top out sides





TFAWS 2011 - August 15-19, 2011

Post Processing

- Surface Thickness vs.
 Time Plots
 - Difficult to accomplish within Thermal Desktop
 - MATLAB script was developed to read data from surface thickness time history file.

clc clear all close all

fid = fopen('came(_ablec__thickness.txt');
 H = textcon(fid, 'is');
 time_records = 102;
 time_records = 102;
 inodes = cell2amt(R(1,1)(2));
 nodes = cell2amt(R(1,1)(2)monOndest));
 data = R(1,1)(monOndest);
 data = cell2amt(R(1,2)(2)monOndest);
 id = terl2amt(data(1)2005);
 data2() = tillatturc(data(1)2005);
 data2() = tillatturc(data(data(1)));

data2 = data2';

j= 1; i = 1; stop = 1; time(i) = data2(j); for i = 2:102 stop = j+numofnodes; data8(:,i-1) = data2(j+1:stop); if i < 102 time(i) = data2(stop+1); end j = stop+1; end beat = x1sread('Chart1,x1s');

figure(1)
[LX,H1,H2] = plotyy(time,data)(3220,i)/0.0254,heat(:,1),heat(:,2));
title('Surface Thickness vs. Time for Fondu Fyre %A-1')
xlabel('Time (sec'))
st(get(At(1),'Timbel'),'String','Surface Thickness (in)')
set(get(At(2),'Timbel'),'String','Beat Face (D)')
grid on



TFAWS 2011 - August 15-19, 2011

14

Results: STS Validation

- CFD Heat Flux Boundary Conditions are stopped after Full Thrust is reached.
- Approximately 0.2" of material loss over 1.3 seconds.
- Post Launch Measurements: 0.25" maximum
- About 0.15 in/s loss
- Reattachment shocks give the highest heat flux and maximum ablation.



Results: SLS Concept

- Approximately 0.15" loss of material over 1.24 sec duration.
- About 0.12 in/s of material loss
- Reattachment shocks happen to be weaker
- Maximum Heat Flux and Ablation at Plume Impingement





TFAWS 2011 - August 15-19, 2011

Conclusions

- Developed analysis methods in Thermal Desktop to perform future heat transfer analyses.
 - Gained knowledge and experience for the capability to utilize the Boundary Condition Mapper to map CFD data to Thermal Desktop[®] Models
 - Gained knowledge and experience for the capability to utilize the ablation subroutine
- Flame Deflector Thermal Analysis
 - The results are within 20% of expected
 - New concepts can be designed to reduce secondary shock wave effects, High Pressure and Temperature.
 - Future analysis will be done to refine results

Acknowledgments

- NASA
- The author would like to acknowledge Cetin Kiris and Emre Sozer of Ames Research Center for their CFD work providing the boundary condition for this Thermal Desktop modeling. This work was funded by the Mobile Launcher Launch Induced Environment project, Task Order 51.



Thank you!

TFAWS 2011 – August 15-19, 2011

19

References

NASA

- SINDA/FLUINT User's Manual
- Thermal Desktop[®] User's Manual