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Development of Quantitative Verification Capabilities for use with RELAP5-3D and R5EXEC

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Outline

- Introduction
- Coverage
- Automated Verification
- Quantitative Pass/Fail Testing
- Quantitative Verification of Coupling
- Conclusions

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Introduction

- Development of code systems requires verification techniques
  - Should ensure proper implementation of numerical methods as well as models and correlations
- Verification process should independently verify these features with each release
  - Should not rely on regression comparisons or “Golden” files
  - Should include the use of quantitative pass/fail metrics
- Process should be automated
  - Reduce resources required to release code versions
  - Should include documentation of verification results
- NNL has developed an automated quantitative verification suite
  - Used with NUPAC and HYDRA – in house versions of RELAP5-3D and R5EXEC

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Coverage

- Coverage matrix is integral to a comprehensive verification suite
- Identifies which verification problems exercise which code features and models
  - Identify which problems and features are included in restart testing
- Can be used for multiple functions
  - Demonstrates which features and models are testing in the verification suite
  - Identifies all of the problems that use each feature or model
- Matrix can be generated manually or automatically

			Tested	Restarted	cpl_cob	cpl_det	cpl_det_new	cpl_det_sa	cpl_det_sas	cpl_drain	cpl_mom	cpl_pvmcore	cpl_pvmcs	cpl_pvmeda	cpl_pvmedca	cpl_pvmedcs	cpl_pvmnd	cpl_pvmpt	cpl_det_kin	cpl_pvmnonc	cpl_nmhstr	cpl_pvmcoresim	cpl_pvmeds	cpl_pvmedacs	cpl_pvmedaps
Explicit Coupling	Parallel	Synchronous	Yes	Yes									R										X	X	X
		Asynchronous	Yes	Yes										R							R			X	X
	Sequential	Synchronous	Yes	Yes												R									
		Asynchronous	Yes	Yes											R										
	Heat Structure	Synchronous	No	No																					
		Asynchronous	Yes	Yes																	R				
	Control System	Synchronous	Yes	Yes	R						X		R						X						
Other T/H Coupling	Semi-Implicit	Synchronous	Yes	Yes	R	X	X			X	X	R					R	R		R					
	Semi-Implicit Momentum Conserving	Synchronous	Yes	No																		X			
	No T/H with other coupling	Synchronous	Yes	No															X						
Kinetics Coupling	Point Power	Synchronous	Yes	Yes	R													R							
	Point volume feedback	Synchronous	Yes	Yes	R													R							
	Point H/S feedback	Synchronous	Yes	Yes	R													R							
	Zone Power	Synchronous	Yes	Yes		X	X										R								
	Zone volume feedback	Synchronous	Yes	Yes		X	X										R								
	Zone H/S feedback	Synchronous	Yes	Yes		X	X										R		X						
	Standalone through HYDRA	Synchronous	Yes	No					X																
		Asynchronous	Yes	No				X																	
	pvmcatchout		Yes	Yes	R	X	X	X	X	X	X	R		R			R	X	X		X	X	X	X	X

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Automated Verification

- To be effective a verification process needs to be **used**
  - Easy to use
  - Fast running
  - Automated

- NUPAC/HYDRA verification is built around “make”
  - Automatically perform parallel operations without special setup
  - Built-in handling of targets and dependencies
    - Allows for staging of executions
    - Allows for fully regressive processing
  - Widely available
  - Allows an easily extensible verification platform
  - HYDRA verification is a sub-set of NUPAC verification suite
    - Separate target within the Makefile

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Automated Verification

- Verification suite identifies simulation failures
  - Message to the user that no failures are detected or which cases have failed
  - Includes failure of post-processing routines
- Automatically identify failures in quantitative testing
- Automation is extended to the generation of documentation

```
NO VERIFICATION FULL BACKUP FAILURES DETECTED

NO VERIFICATION HYDRO BACKUP FAILURES DETECTED

NO VERIFICATION FAILURES DETECTED

NO VERIFICATION GO/NOGO FAILURES DETECTED

NO VERIFICATION RESTART DIFFERENCES DETECTED

NO VERIFICATION RESTART OF RESTART  FAILURES DETECTED
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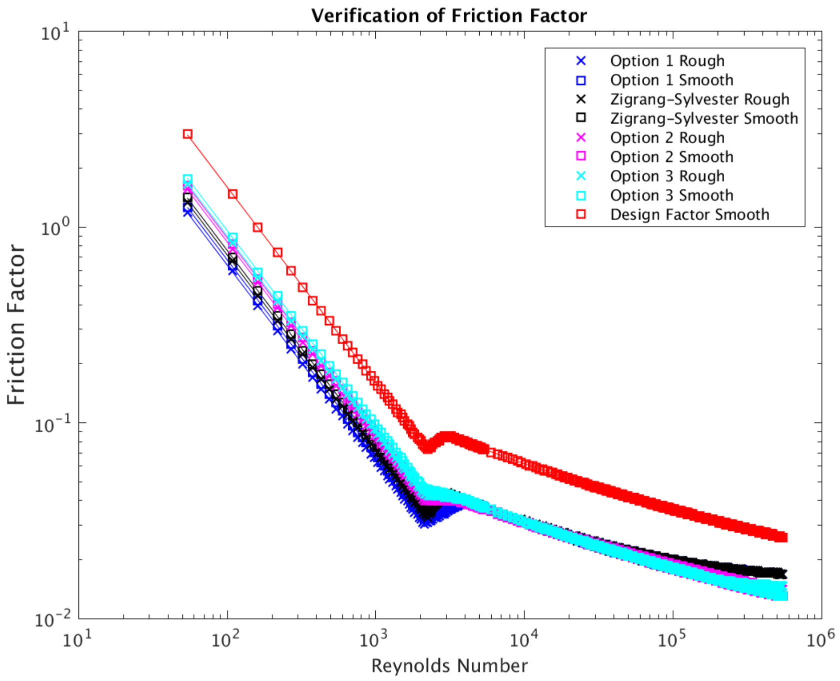
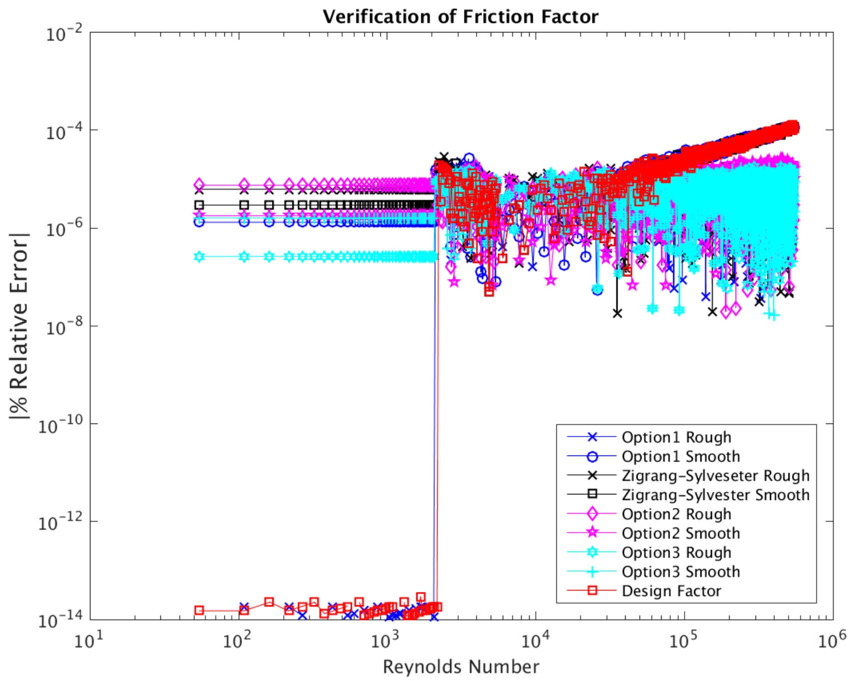
Quantitative Pass/Fail Testing

Verification of code correlations

- e.g. Fiction factor correlation and frictional pressure drop

- Independent calculations are performed
  - $f\left(Re, \frac{\epsilon}{D}\right)$
  - Using conditions from the model (u, ρ, μ)
- Compare independent calculation to code results





Attribute	Problem	Limit	Value	Pass/Fail	Comments
Zigrang-Sylvester	fric_fac	1.000000e-03	1.224123e-04	Pass	Zigrang-Sylvester Correlation
Option1	fric_fac	1.000000e-03	1.200681e-04	Pass	NUPAC option 1 correlation
Option2	fric_fac	1.000000e-03	2.683179e-05	Pass	NUPAC option 2 correlation
Option3	fric_fac	1.000000e-03	1.949757e-05	Pass	NUPAC option 3 correlation
Design	fric_fac	1.000000e-03	1.242263e-04	Pass	Design Factor
FricDp	fric_fac	1.000000e-01	1.399884e-04	Pass	Frictional Pressure Drop
K re	fric_fac	1.000000e-06	4.730701e-07	Pass	Reynolds Number Dependent K-factor
Seider-Tate novisc	heatd_wall	1.000000e-01	0.000000e+00	Pass	Seider-Tate no viscosity, heated wall correction factor
Seider-Tate visc	heatd_wall	1.000000e-01	0.000000e+00	Pass	Seider-Tate w/ viscosity, heated wall correction factor
Option1	heatd_wall	1.000000e-01	0.000000e+00	Pass	NUPAC Option1, heated wall correction factor

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Quantitative Verification of Coupling

- Explicit Coupling

Attribute	Problem	Limit	Value	Pass/Fail	Comments
coupled volume	cpl_pvmcs	1.000000e-06	0.000000e+00	Pass	Explicit parallel synchronous coupling volume and junction quantities
coupled junction	cpl_pvmeda	1.000000e-06	0.000000e+00	Pass	Explicit parallel asynchronous coupling junction instantaneous flow at coupling times
coupled volume	cpl_pvmeda	1.000000e-06	0.000000e+00	Pass	Explicit parallel asynchronous coupling volume quantities at coupling times
coupled junction	cpl_pvmedacs	1.000000e-06	0.000000e+00	Pass	Explicit parallel asynchronous coupling junction instantaneous flow at coupling times
coupled volume	cpl_pvmedacs	1.000000e-06	0.000000e+00	Pass	Explicit parallel asynchronous coupling volume quantities at coupling times
coupled junction	cpl_pvmedaps	1.000000e-06	0.000000e+00	Pass	Explicit parallel asynchronous coupling junction instantaneous flow at coupling times
coupled volume	cpl_pvmedaps	1.000000e-06	0.000000e+00	Pass	Explicit parallel asynchronous coupling volume quantities at coupling times
coupled junction	cpl_pvmedca	1.000000e-06	0.000000e+00	Pass	Explicit sequential asynchronous coupling junction integrated flow at coupling times
coupled volume	cpl_pvmedca	1.000000e-06	0.000000e+00	Pass	Explicit sequential asynchronous coupling volume quantities at coupling times
coupled junction	cpl_pvmedcs	1.000000e-06	0.000000e+00	Pass	Explicit sequential synchronous coupling junction integrated flow
coupled volume	cpl_pvmedcs	1.000000e-06	0.000000e+00	Pass	Explicit sequential synchronous coupling volume quantities
coupled junction	cpl_pvmeds	1.000000e-06	0.000000e+00	Pass	Explicit parallel synchronous coupling junction instantaneous flow at coupling times
coupled volume	cpl_pvmeds	1.000000e-06	0.000000e+00	Pass	Explicit parallel synchronous coupling volume quantities at coupling times

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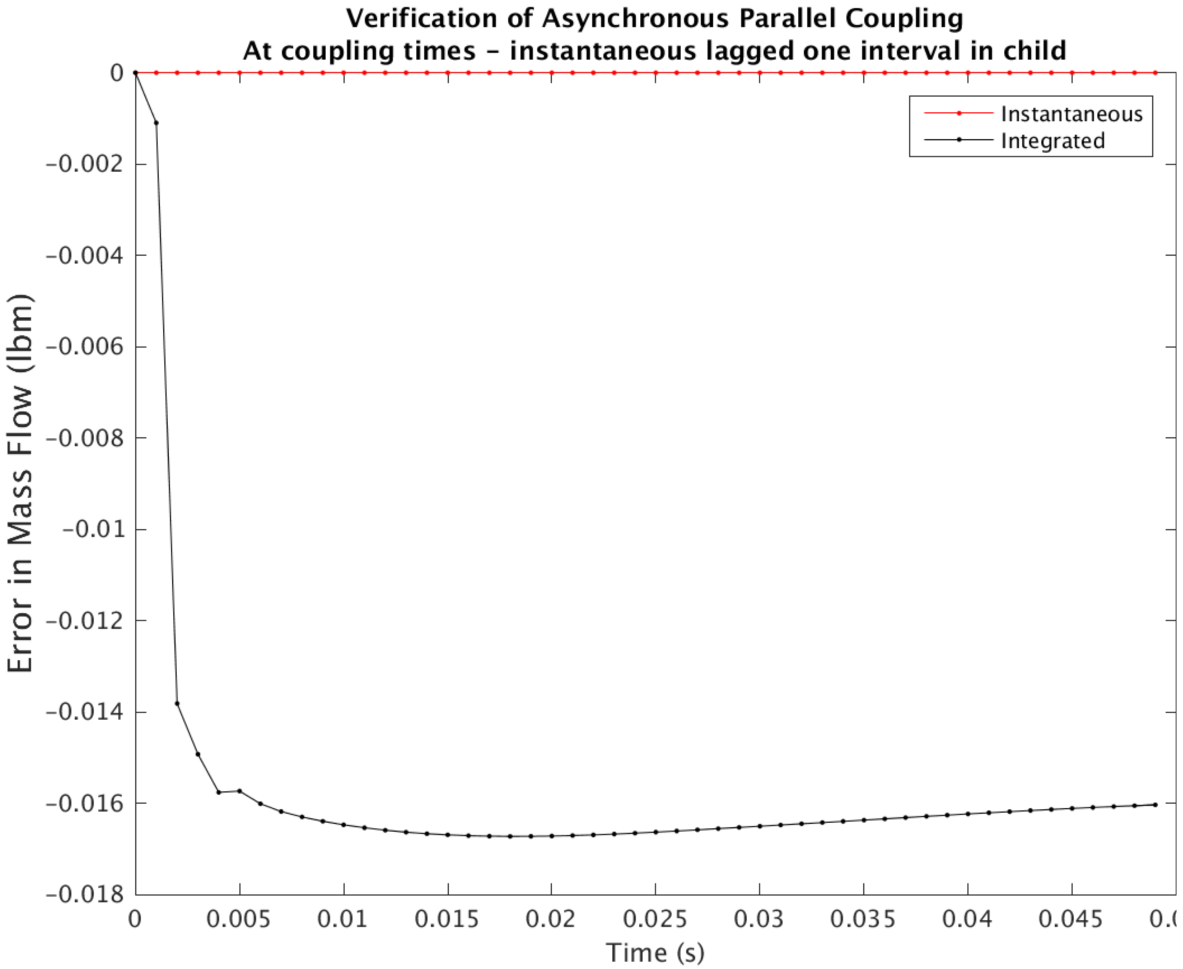
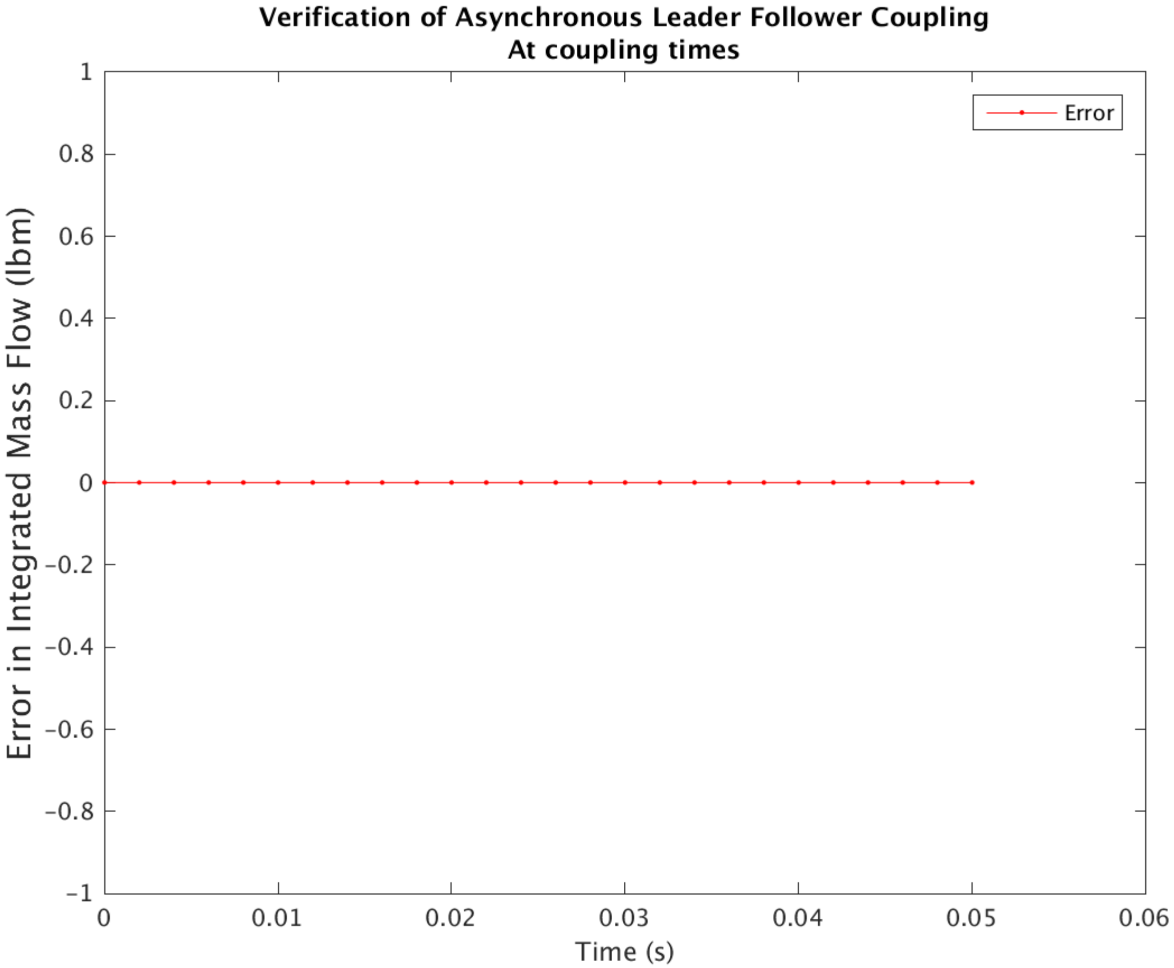
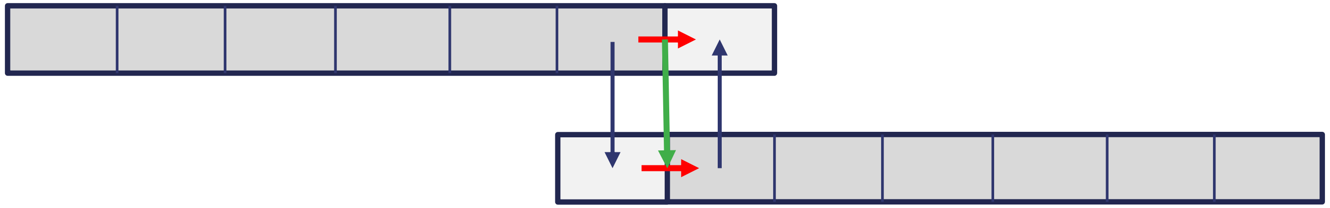
Quantitative Verification of Coupling







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Quantitative Verification of Coupling

- Semi-Implicit Coupling – includes calculation of coupled pressures

Attribute	Problem	Limit	Value	Pass/Fail	Comments
coupled pressure	cpl_cob	2.000000e-04	1.864387e-04	Pass	Semi-implicit coupling; relative error in coupled pressures between NUPAC and COBRA
coupled pressure	cpl_mom	2.000000e-04	1.893863e-04	Pass	Semi-implicit coupling; relative error in coupled pressures between NUPAC and COBRA
csa pres	cpl_pvmcore	1.000000e-06	0.000000e+00	Pass	Comparison of coupled volume pressure to standalone problem
csa vel	cpl_pvmcore	1.000000e-06	0.000000e+00	Pass	Comparison of coupled junction velocity to standalone problem
coupled junction	cpl_pvmcore	1.000000e-06	0.000000e+00	Pass	Comparison of semi-implicit coupled junction quantities
coupled pressure	cpl_pvmcore	1.000000e-06	0.000000e+00	Pass	Comparison of semi-implicit coupled volume pressures
csa pres	cpl_pvmcoresim	1.000000e-06	0.000000e+00	Pass	Comparison of coupled volume pressure to standalone problem
csa vel	cpl_pvmcoresim	1.000000e-06	0.000000e+00	Pass	Comparison of coupled junction velocity to standalone problem
coupled junction	cpl_pvmcoresim	1.000000e-06	0.000000e+00	Pass	Comparison of semi-implicit coupled junction quantities
coupled pressure	cpl_pvmcoresim	1.000000e-06	0.000000e+00	Pass	Comparison of semi-implicit coupled volume pressures
csa pres	cpl_pvmnonc	1.000000e-03	1.220703e-04	Pass	Comparison of coupled volume pressure to standalone problem
csa vel	cpl_pvmnonc	1.000000e-03	4.768372e-07	Pass	Comparison of coupled junction velocity to standalone problem
csa qualan	cpl_pvmnonc	1.000000e-06	0.000000e+00	Pass	Comparison of coupled volume quala(n) to standalone problem
coupled junction	cpl_pvmnonc	1.000000e-06	0.000000e+00	Pass	Comparison of semi-implicit coupled junction quantities
coupled pressure	cpl_pvmnonc	1.000000e-06	0.000000e+00	Pass	Comparison of semi-implicit coupled volume pressures
coupled qualan	cpl_pvmnonc	1.000000e-06	0.000000e+00	Pass	Comparison of semi-implicit coupled volume qualan

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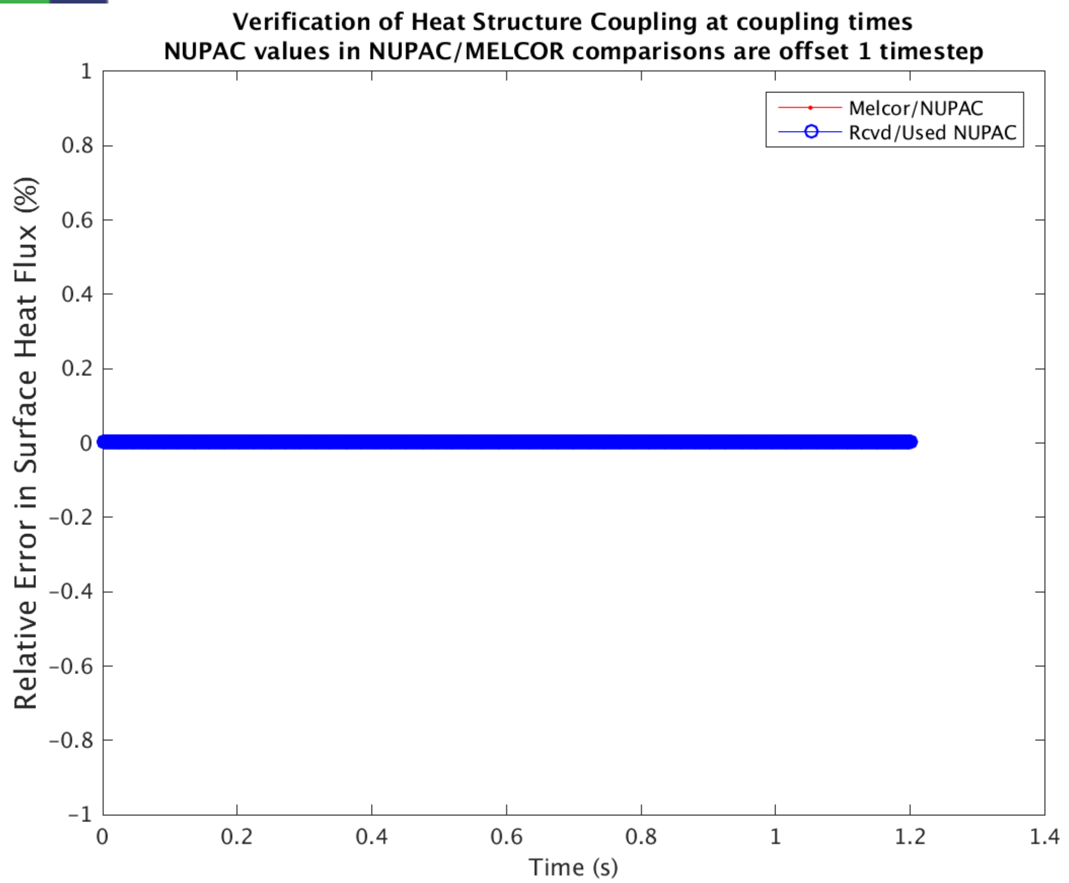
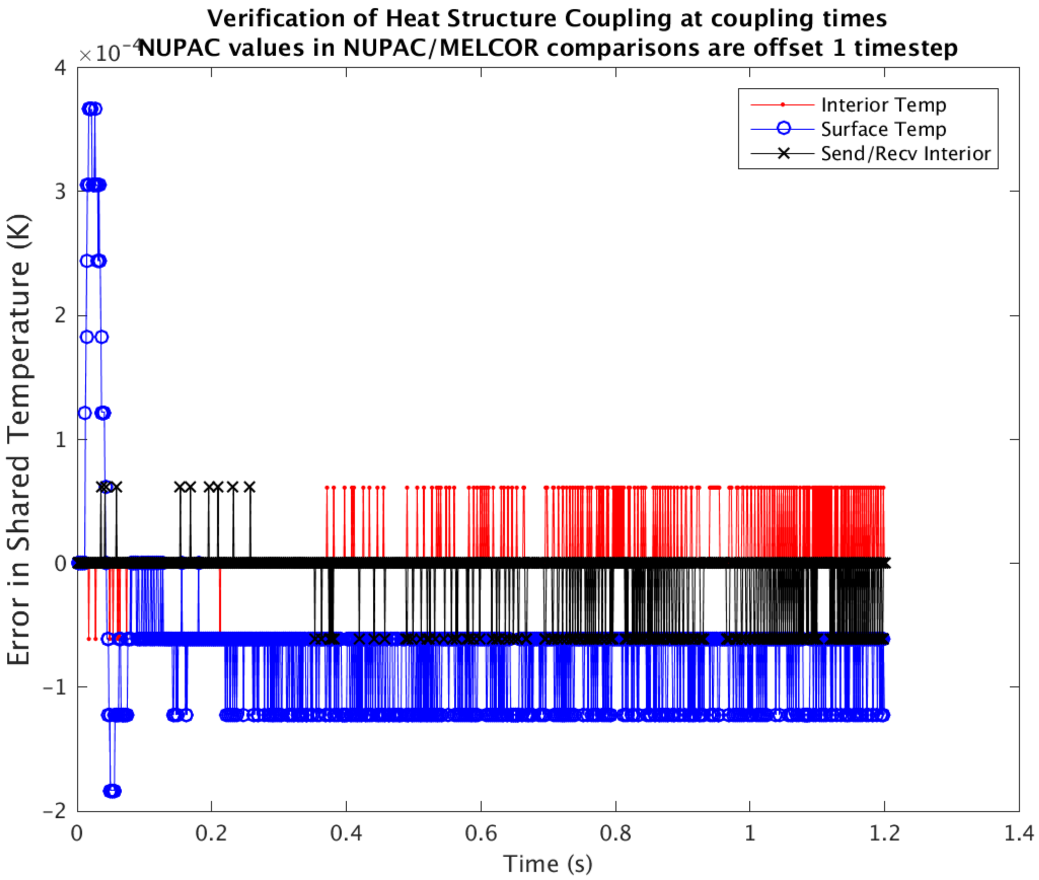
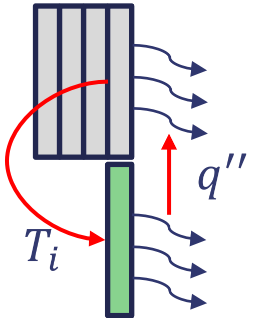
Quantitative Verification of Coupling





Attribute	Problem	Limit	Value	Pass/Fail	Comments
nm temp	cpl_nmhstr	1.000000e-03	3.662109e-04	Pass	Comparison of nupac node temperature to melcor temperature
nm qflux	cpl_nmhstr	1.000000e-04	0.000000e+00	Pass	Comparison of nupac surface heat flux to melcor heat flux
nm temp	cpl_nmhstrs	1.000000e-03	3.662109e-04	Pass	Comparison of nupac node temperature to melcor temperature
nm qflux	cpl_nmhstrs	1.000000e-04	0.000000e+00	Pass	Comparison of nupac surface heat flux to melcor heat flux



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Conclusions

- An automated, quantitative, verification process has been developed for use with NUPAC and HYDRA and can be extended to RELAP5-3D and R5EXEC

- Quantitative pass/fail metrics to demonstrate verification status

- Allows positive verification of code features with each release
  - Does not rely upon daisy chain verification
  - Does not rely upon golden files

- Automation enables **use**
  - Easy to use and fast running
  - Includes identification of code failures or failing performance

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