https://ntrs.nasa.gov/search.jsp?R=20140012588 2019-08-31T18:05:11+00:00Z

View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by NASA Technical Reports Server

A Monte Carlo Analysis of the Thrust Imbalance for the Space Launch System Booster during Both the Ignition Transient and Steady State Operation

by

Winfred A. Foster, Jr.
Auburn University
Winston Crowder
Lockheed-Martin Corporation
Todd E. Steadman
NASA/Marshall Space Flight Center

Objective

- To provide an estimate of the thrust imbalance versus time for the SLS solid rocket motor booster from ignition through tail-off

Approach

- Couple a Monte Carlo analysis code with two legacy codes previously used for the internal ballistic analysis of the Space Shuttle solid rocket motor boosters
- The ignition transient analysis used the code developed by Caveny and Kuo for the analysis of ignition transients in large segmented solid rocket motors

Approach

- The steady state analysis was based on the simplified internal ballistics code developed by Sforzini, et.al., for large L/D solid rocket motors and which had been used in conjunction with the Monte Carlo analysis for the Space Shuttle boosters
- A MATLAB shell program was used to manage the execution, data input and graphical output for each of the codes

Approach

- A statistical sample of 2000 solid rocket motors or 1000 pairs of boosters was generated using the Monte Carlo analysis for both ignition transient and steady state motor operation
- Pairs of motors were constructed by putting an odd numbered motor with an even numbered motor

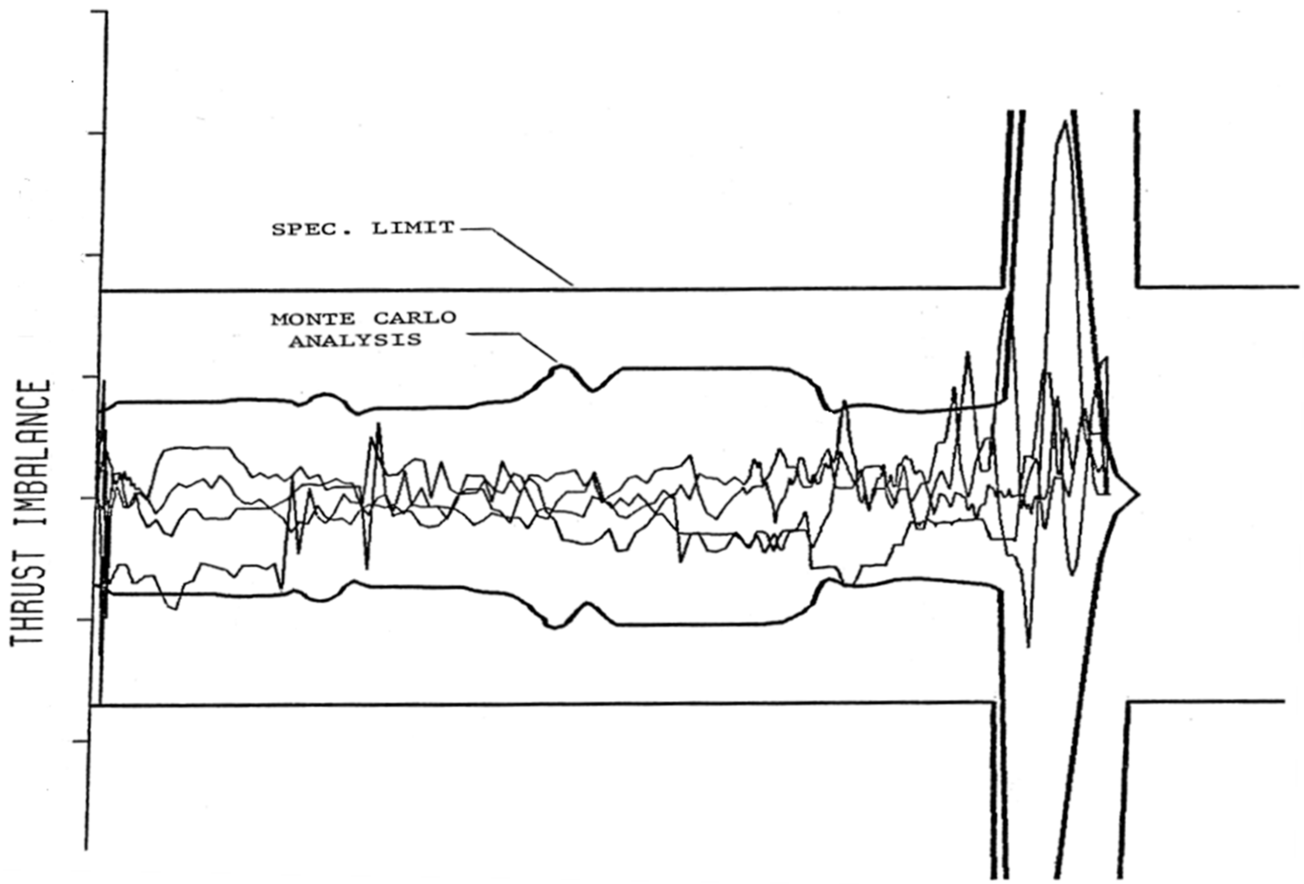
Approach

- Statistical variations in performance properties were allowed between motors of the entire population and between motors of a single pair
- The thrust imbalance in each analysis was determined by selecting a set of specific time points and determining the difference in thrust between the two motors of a pair at those times

Approach

- Given the thrust imbalance versus time data, a thrust imbalance envelope about a zero mean value was determined by calculating the K-sigma value at each time point
- The predicted thrust imbalance envelope was then compared to the operational specification limit for thrust imbalance versus time provide by NASA/MSFC
- The validity of this approach was verified previously using data obtained from Space Shuttle Flights for the steady state and tail-off portions of the thrust time trace

Space Shuttle Flight Data Comparison



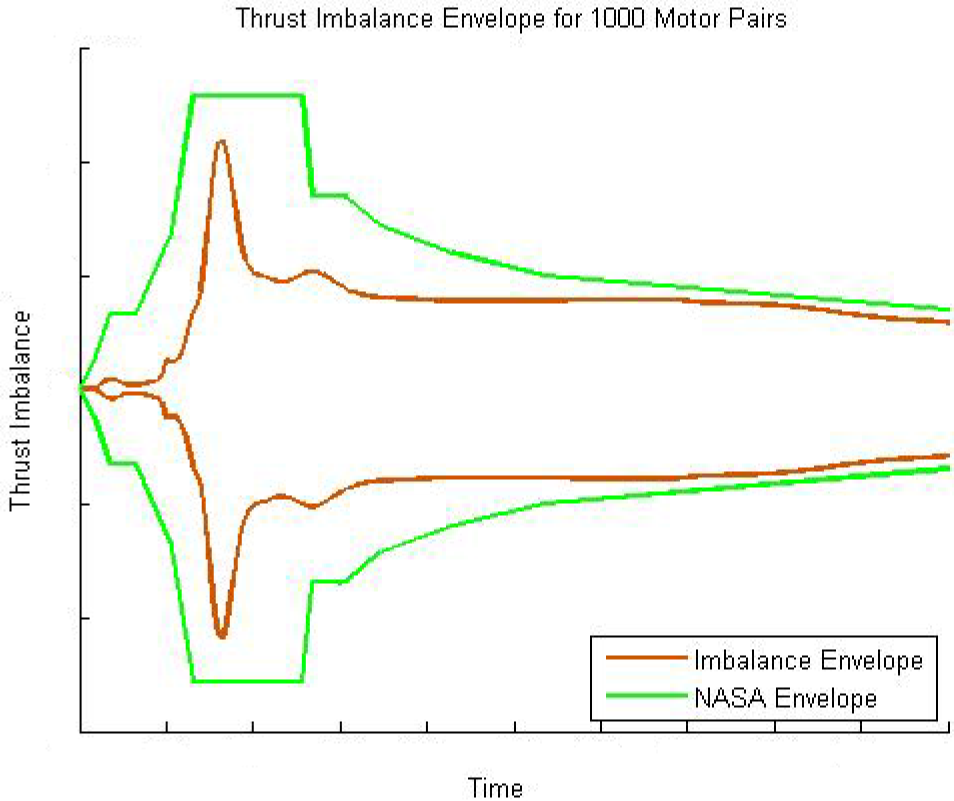
Ignition Transient Thrust Imbalance

Ignition Transient Variables

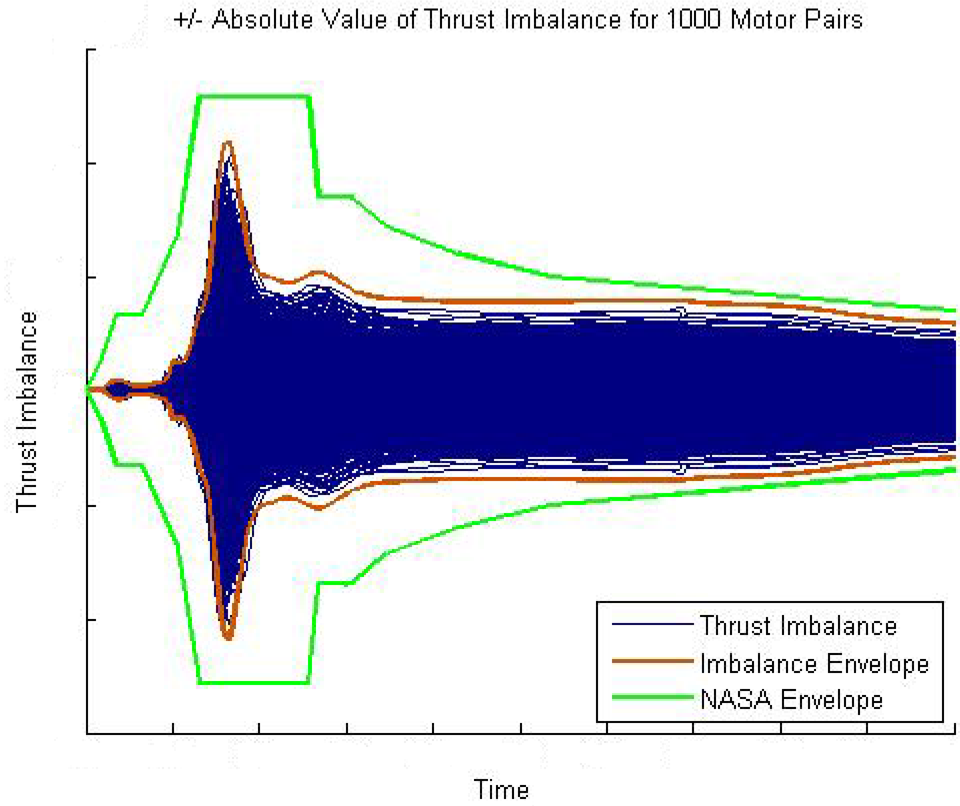
Variable Name	Variable Definition
TPI	initial propellant grain temperature
AT	nozzle throat area
XP	location where propellant begins
XG	aft end of propellant
XE	end of flow passage
GAMA	ratio of specific heats
W	molecular weight of combustion gases
TIGN	igniter gas mean temperature
TFREF	reference adiabatic flame temperature
RUFSUR	port wall roughness
FKPR	propellant thermal conductivity
ROPR	propellant density
CPR	propellant specific heat
TOREF	reference propellant temperature
SIGP	temperature sensitivity of burning rate a constant pressure
TPSCRI	surface ignition temperature
RREF	reference burning rate
PREF	propellant property reference temperature
BREXP	burning rate exponent
EBC	Robillard-Lenoir constant
EBEX	Robillard-Lenoir constant
DE	diameter of the nozzle exit plane
CM	nozzle thrust loss coefficient
EROAT	nozzle erosion parameter
EROEXP	nozzle erosion parameter
ALFAD	nozzle divergence half-angle
TPSHFT	reference PMBT difference between motors of a single pair
BRSHFT	reference burning rate shift between motors of a single pair
ATSHFT	reference throat area shift between motors of a single pair
DPSHFT`	reference propellant density shift between motors of a single pair
DESHFT	reference exit diameter shift between motors of a single pair
ETSHFT	reference throat erosion rate shift between motors of a single pair
SHFTMI	reference Δt time shift in mass addition versus time from the igniter

Ignition Transient Thrust Imbalance Envelopes

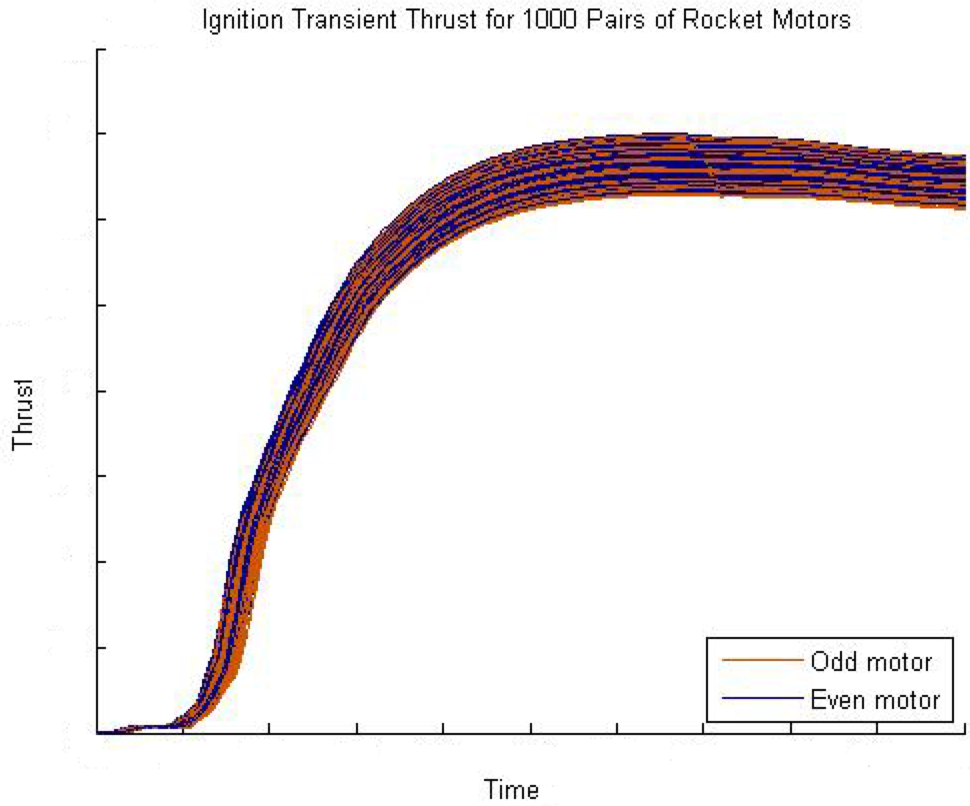
PMBT 40º-90º F (K=3.472)



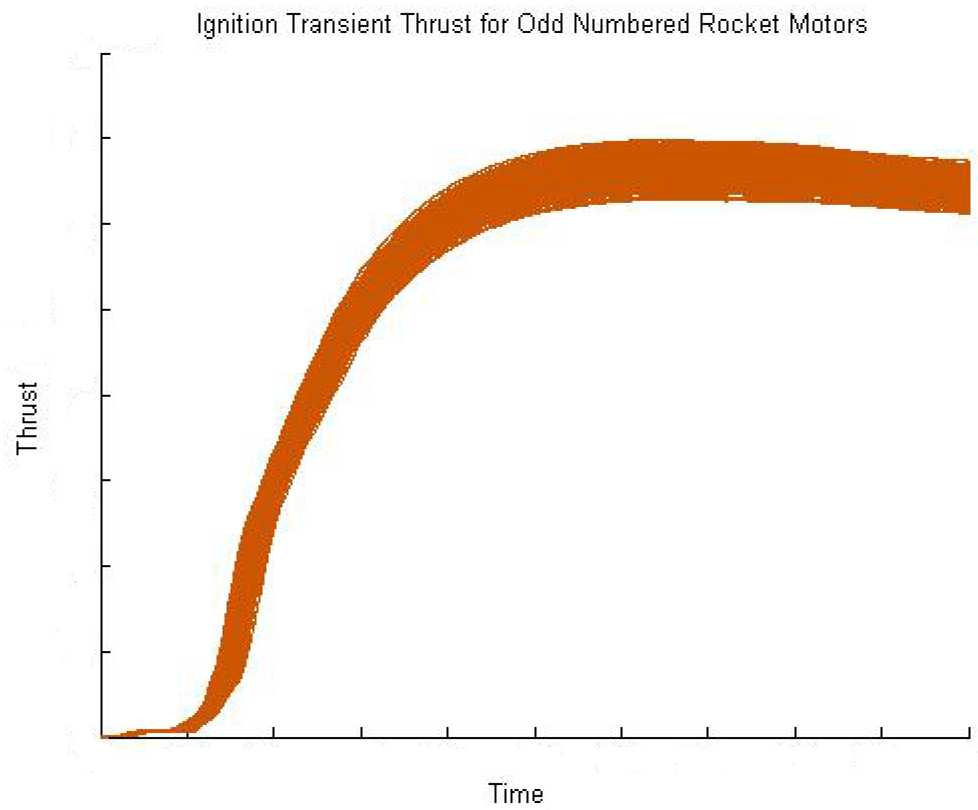
Ignition Transient Thrust Imbalance Envelopes PMBT 40º-90º F (K=3.472)



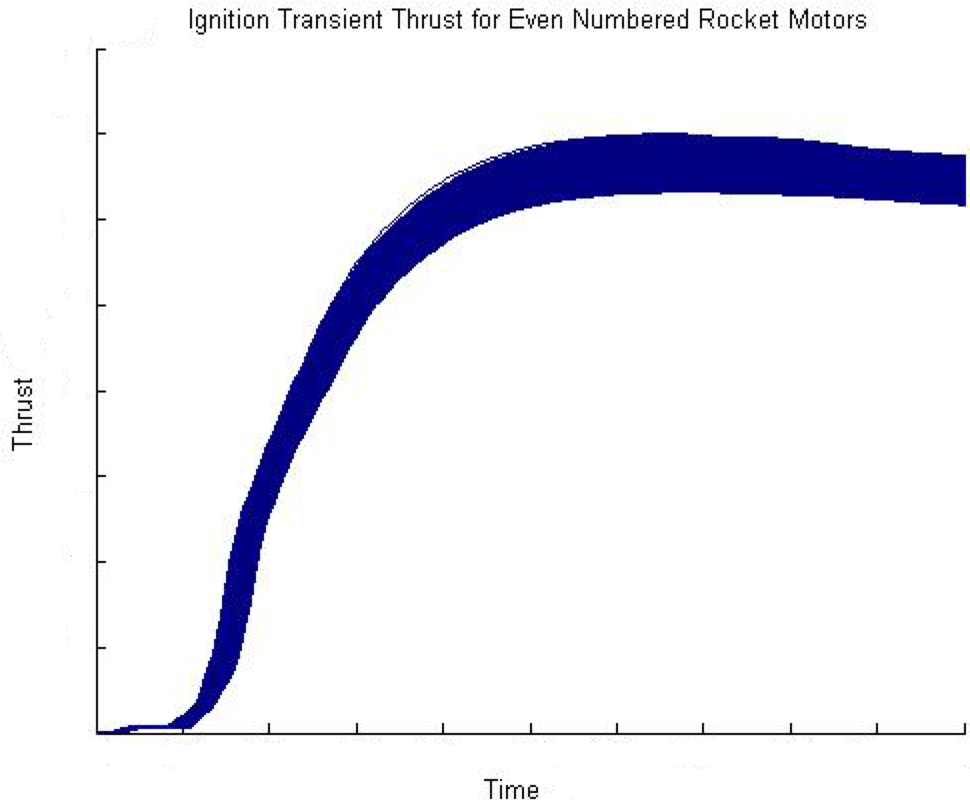
Thrust Time Traces
PMBT 40º-90º F



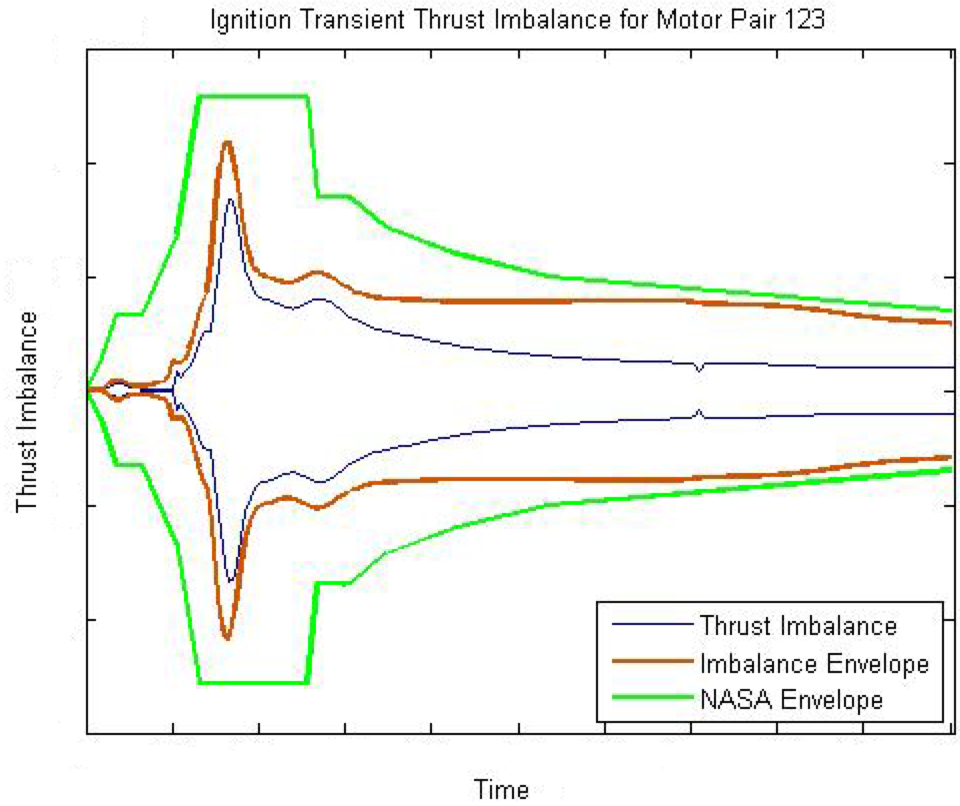
Thrust Time Traces
PMBT 40º-90º F



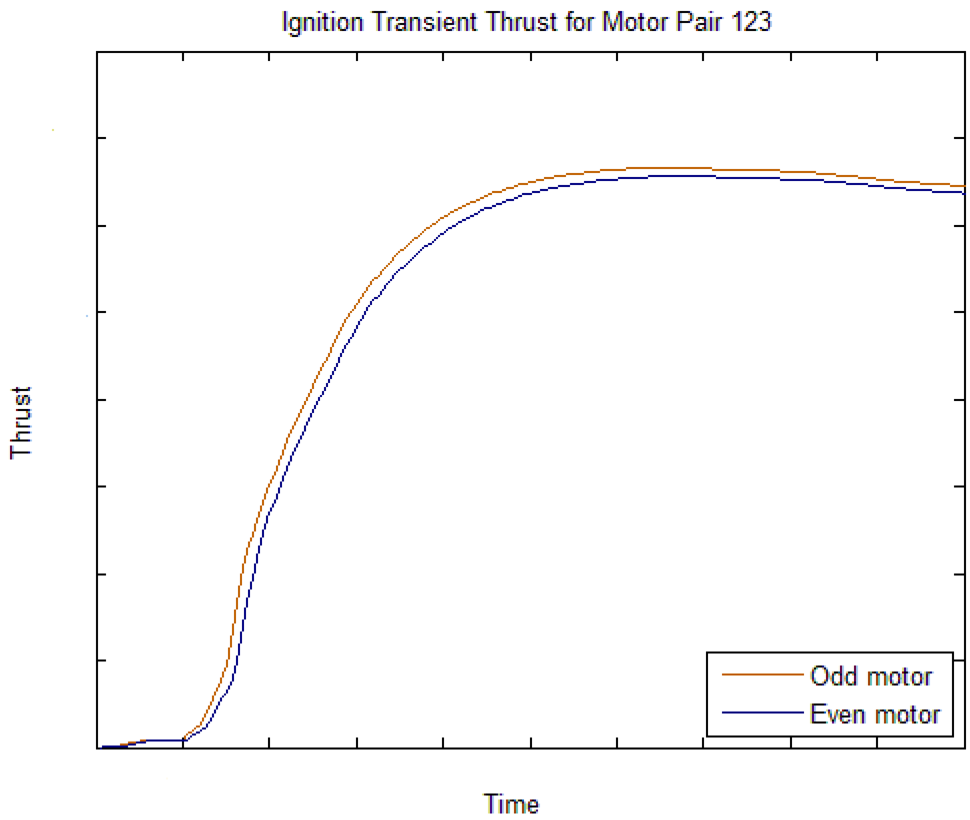
Thrust Time Traces
PMBT 40^o-90^o F



Typical Ignition Transient Thrust Imbalance PMBT 40^{o}-90^{o} F (K=3.472)



Typical Thrust Time Traces
PMBT 40º-90º F

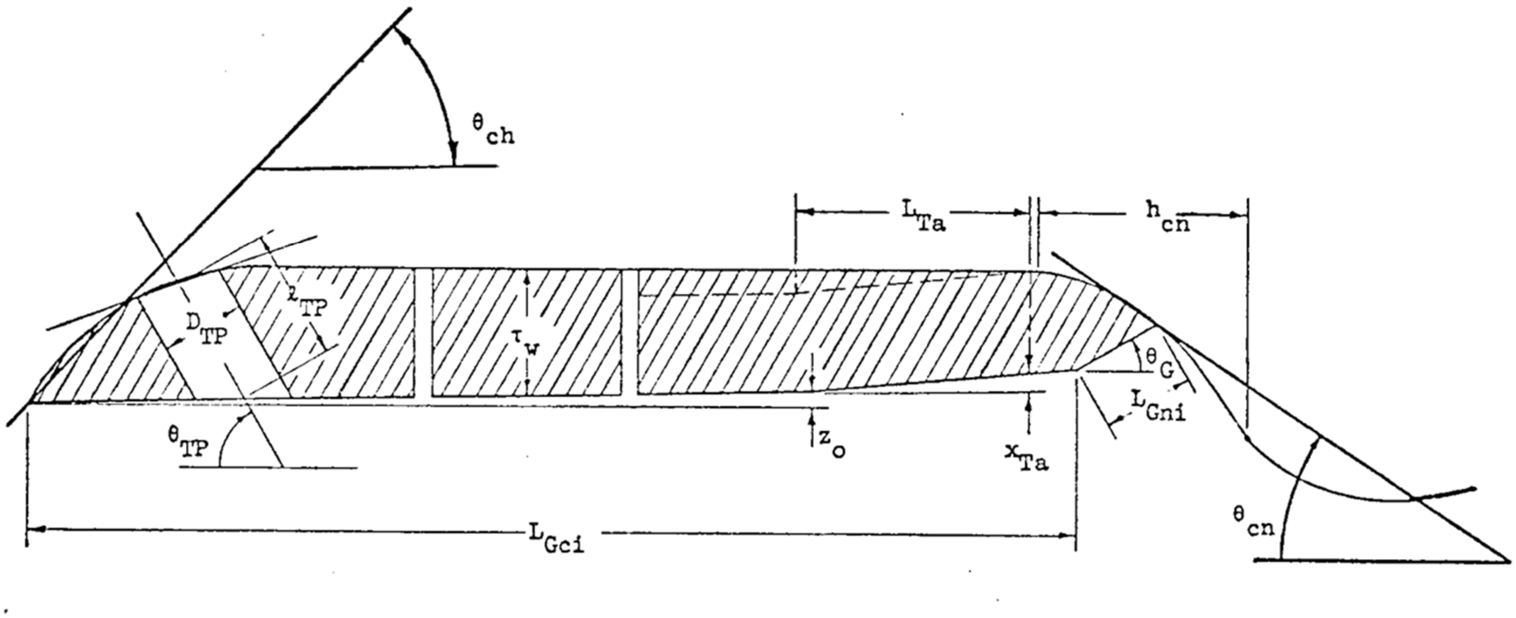


Steady State and Tail-Off Thrust Imbalance

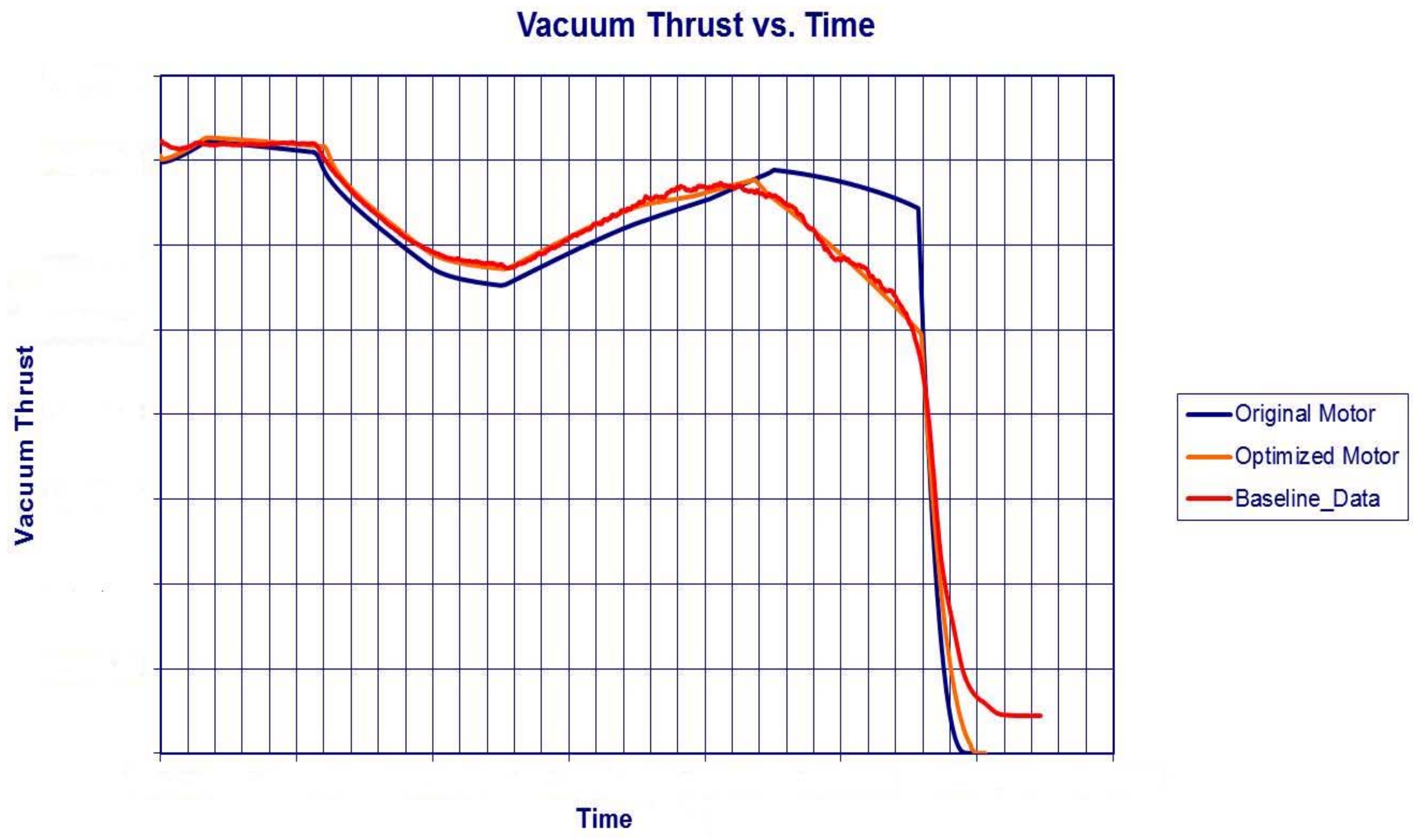
Definition of Nominal Motor

- Required since the simplified internal ballistics code does not rigorously account for all of the 3D motor geometry, particularly in the aft end, head end dome and star to CP transition
- Used a design optimization approach to determine the adjustments to the code geometric variables to match the thrust time trace obtained from static test data
- This approach is valid since the thrust imbalance only involves Δ's between motors of a pair

Typical Grain Design Variables



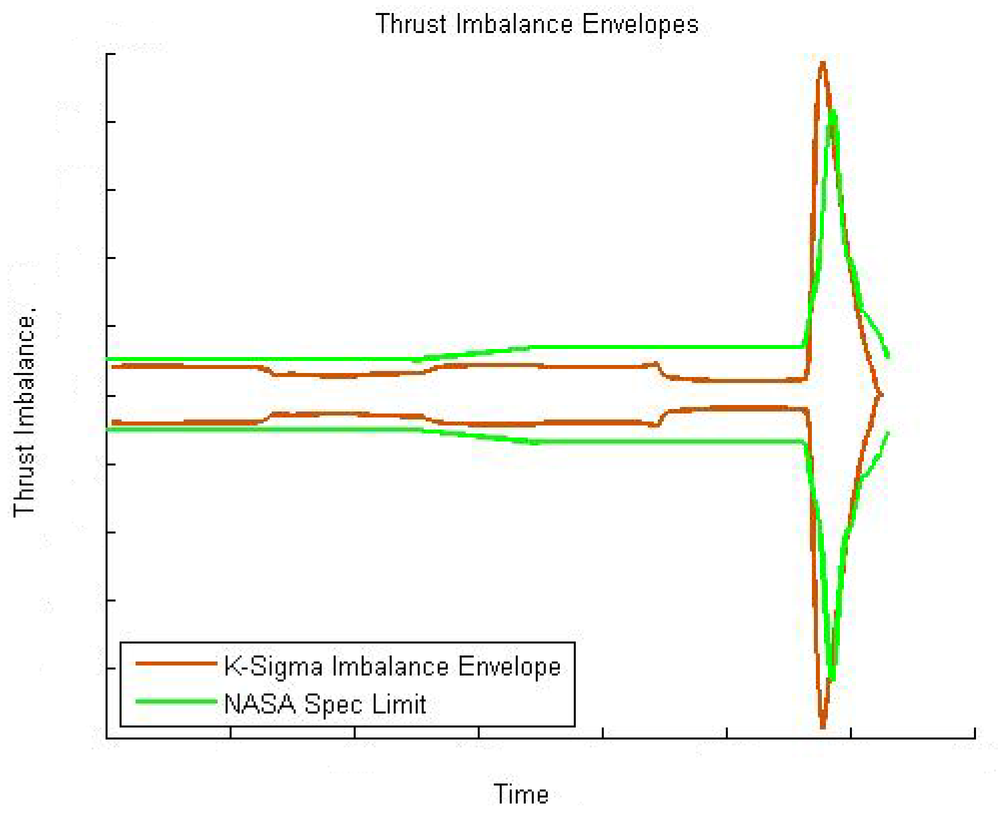
Thrust Time Trace to Establish Nominal Motor Performance



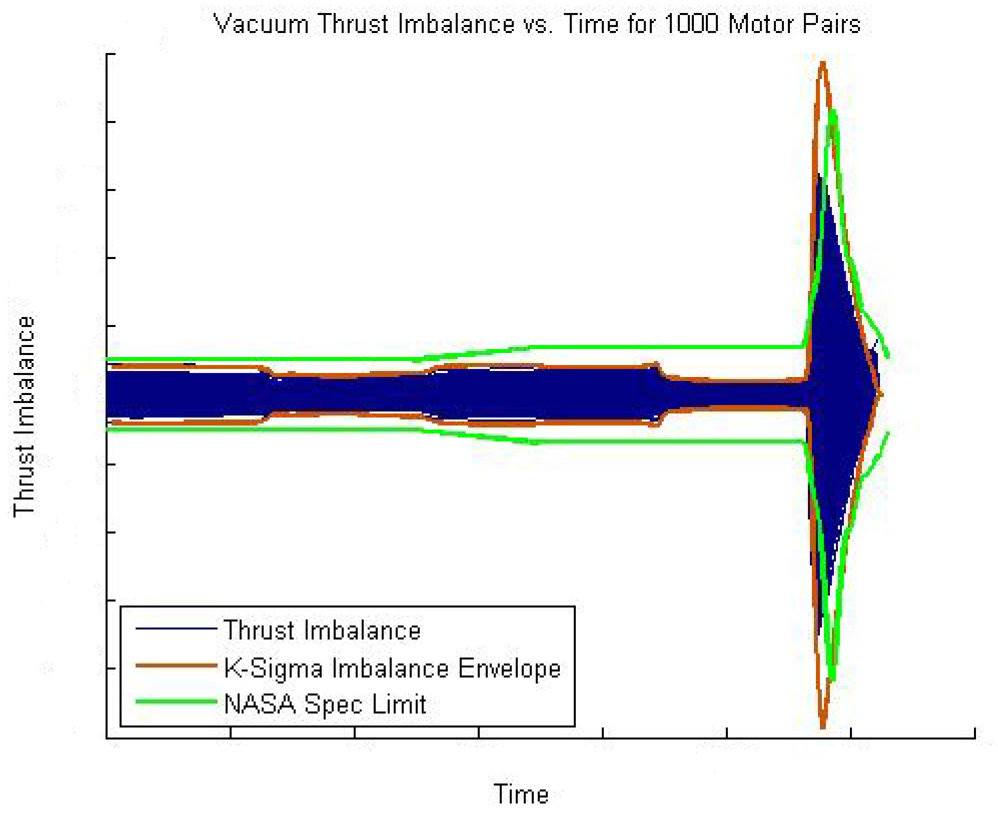
Steady State & Tail-Off Variables

Variable Name	Variable Definition
RHO	propellant Density
A1	burning rate coefficient
A1SHFT	reference burn rate coefficient shift between motors of a single pair
N1	burning rate exponent
ALPHA	erosive burning rate coefficient
BETA	erosive burning rate coefficient
ROAL	oxidizer to aluminum ratio
DE	exit plane diameter
DTI	initial throat diameter
THETA	cant angle of the nozzle
ALFAN	nozzle cone half-angle
XT	aft end taper dimension
ZO	aft end taper dimension
ZC	aft end taper dimension
RONDCN	nozzle end case out of roundness parameter
RONDCH	head end case out of roundness parameter
RONDGN	nozzle end grain out of roundness parameter
RONDGH	head end grain out of roundness parameter
EXN	eccentricity in x at nozzle end
EYN	eccentricity in y at nozzle end
EXH	eccentricity in x at head end
EYH	eccentricity in y at head end
ALPHAH	angular orientation of ovality at nozzle end
ALPHAN	angular orientation of ovality at head end
ERREF	reference throat erosion rate
TGR	grain bulk temperature
TGSHFT	reference PMBT difference between motors of a single pair
DO	outside CP grain diameter
DI	initial inside CP grain diameter
THETAG	aft end taper angle
LGCI	initial length of CP propellant grain
LGNI	aft end tapered grain length
THETCN	nozzle end closure angle
THETCH	head end closure angle
RC	propellant star grain outside radius
FILL	star valley fillet radius
RP	initial radius of truncated star
RIS	initial radius at the bottom of the truncated star slot

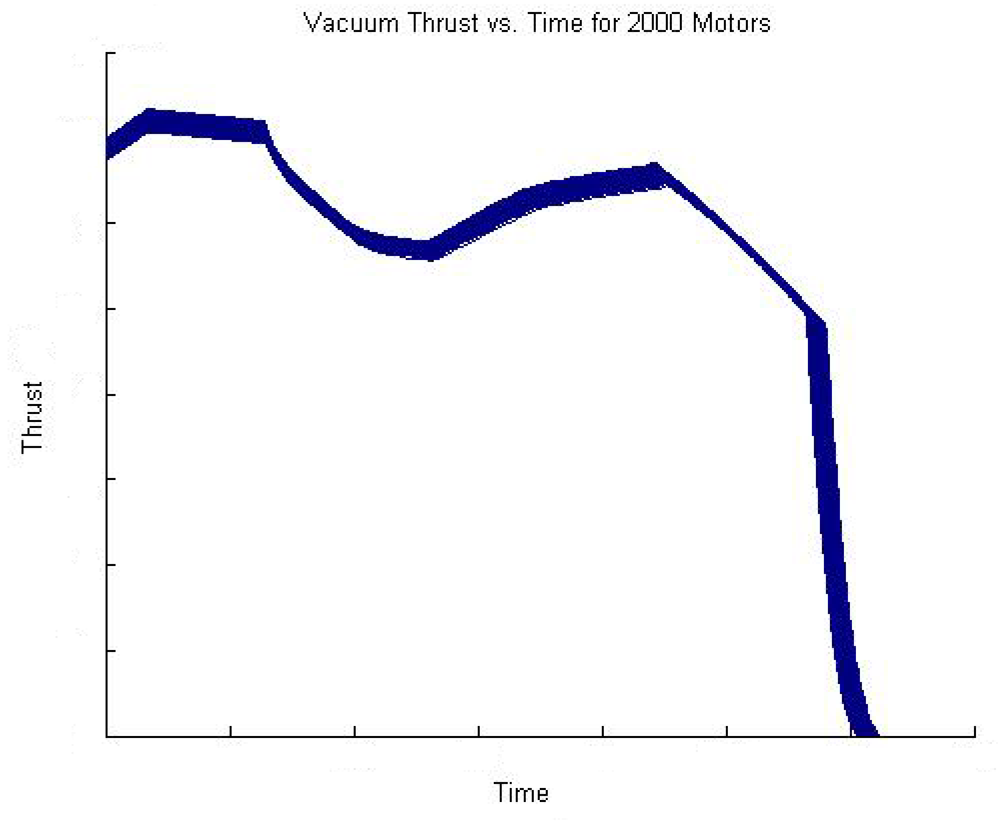
Steady State Thrust Imbalance Envelopes PMBT 60^o F (K=3.472)



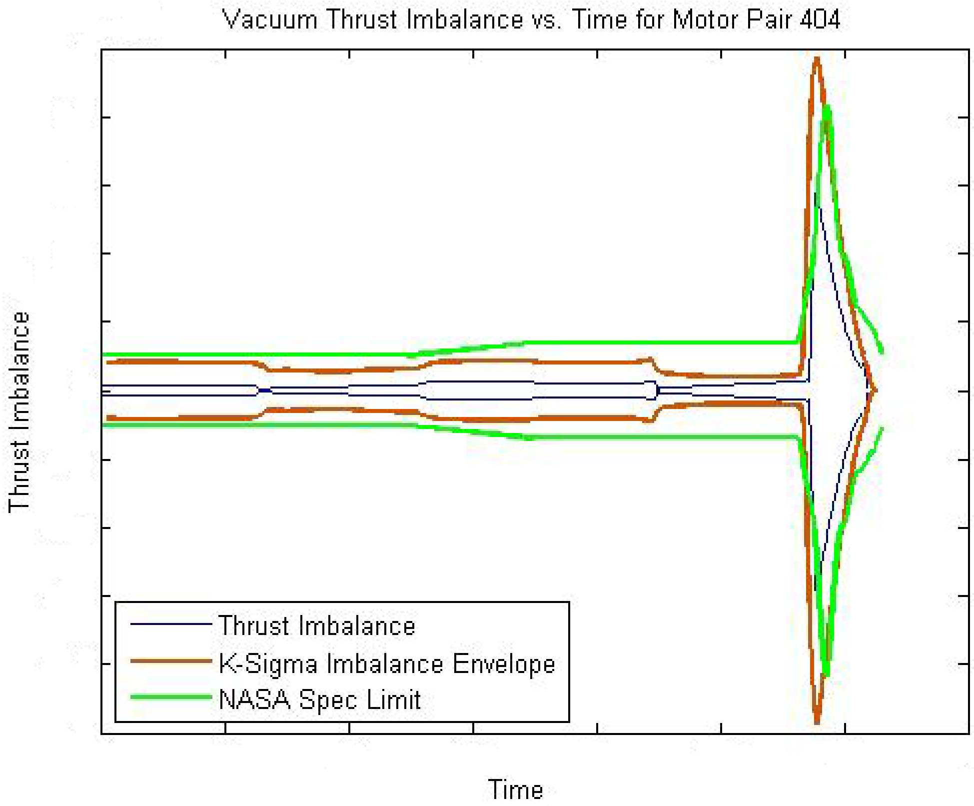
Steady State Thrust Imbalance Envelopes PMBT 60^{o} F (K=3.472)



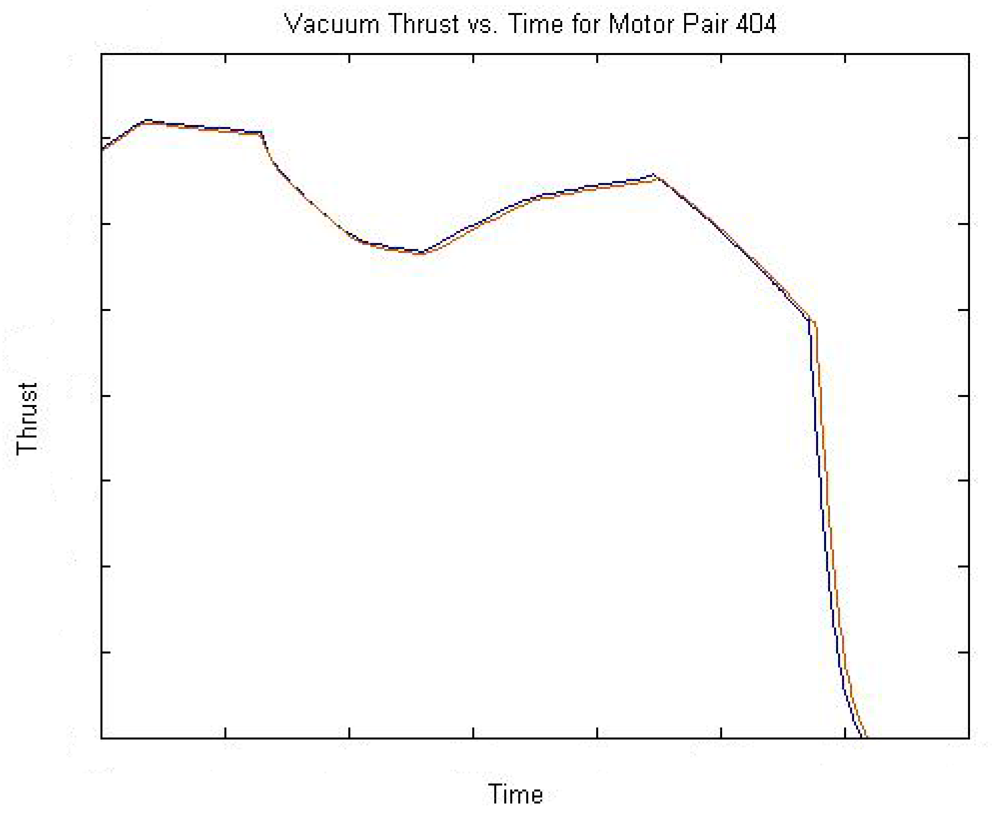
Thrust Time Traces
PMBT 60° F (K=3.472)



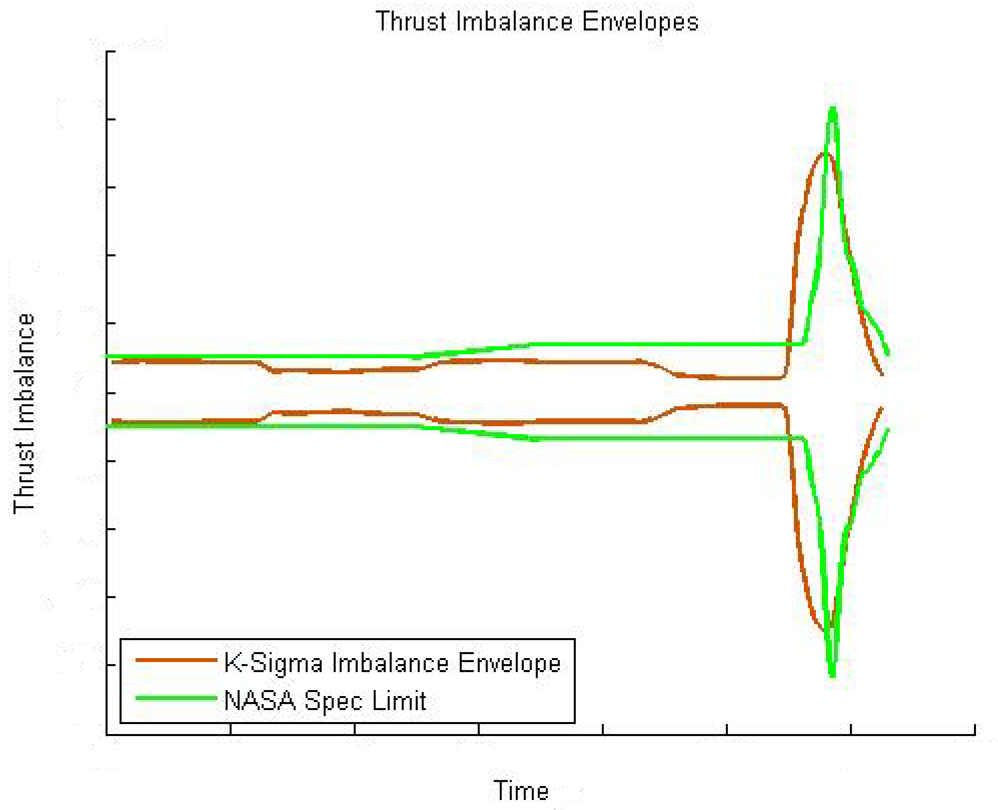
Typical Steady State Thrust Imbalance PMBT 60º F (K=3.472)



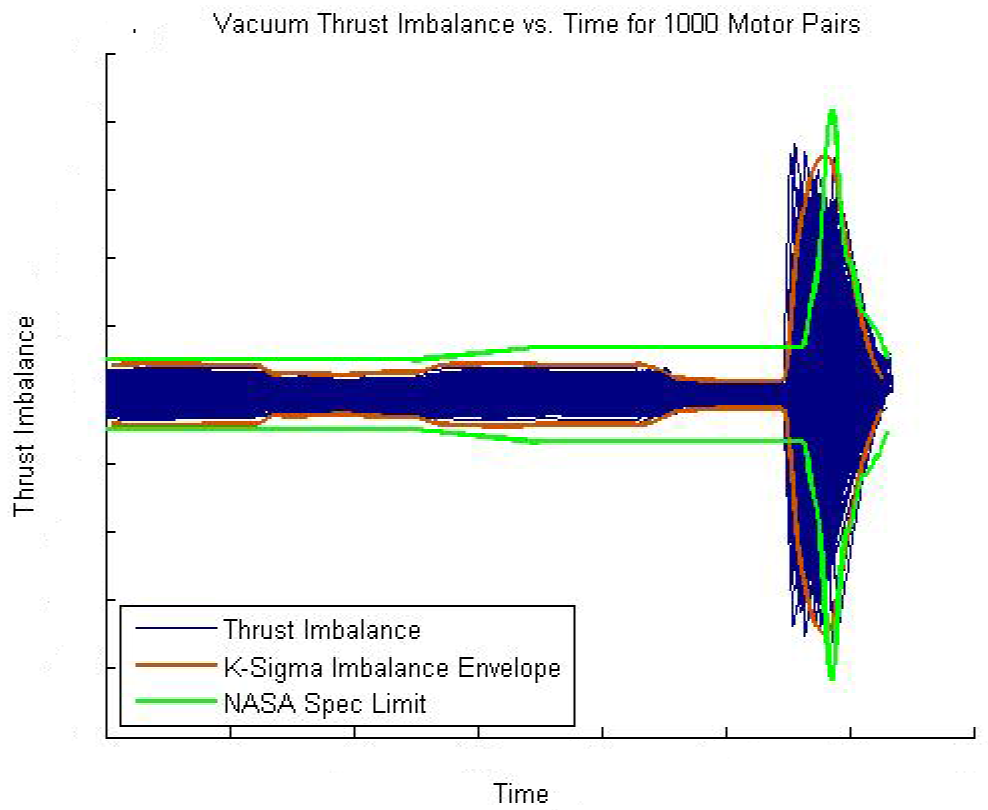
Typical Steady State Thrust Time Traces PMBT 60º F



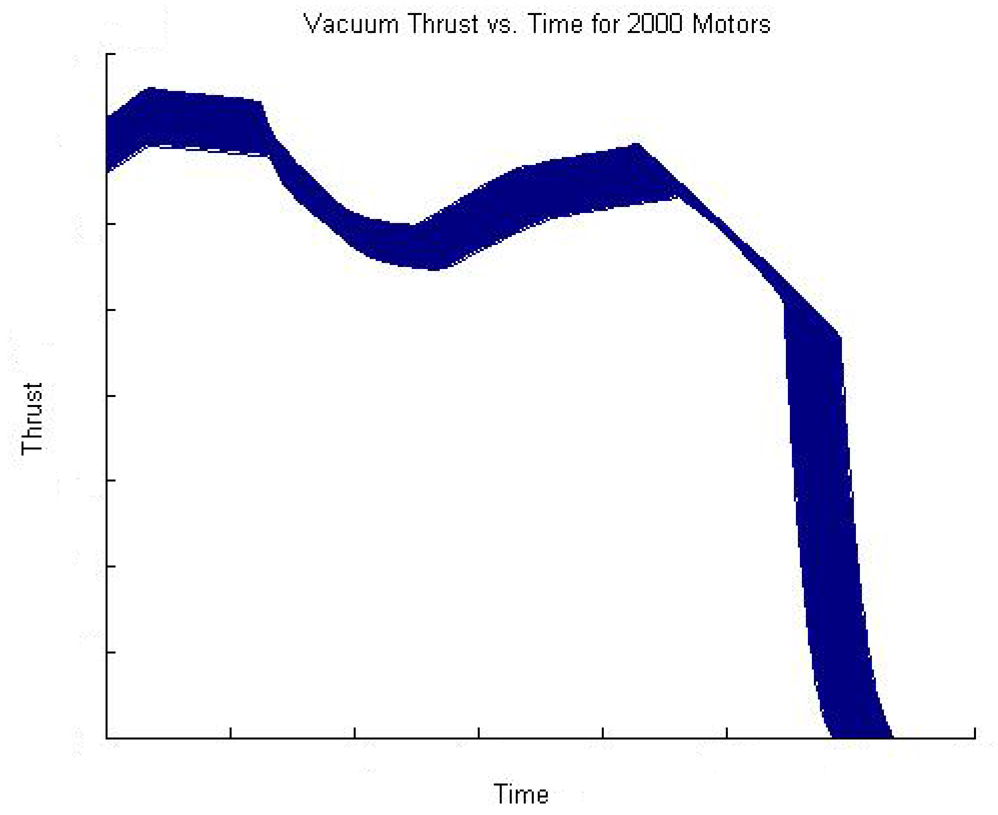
Steady State Thrust Imbalance Envelopes PMBT 40º-90º F (K=3.472)



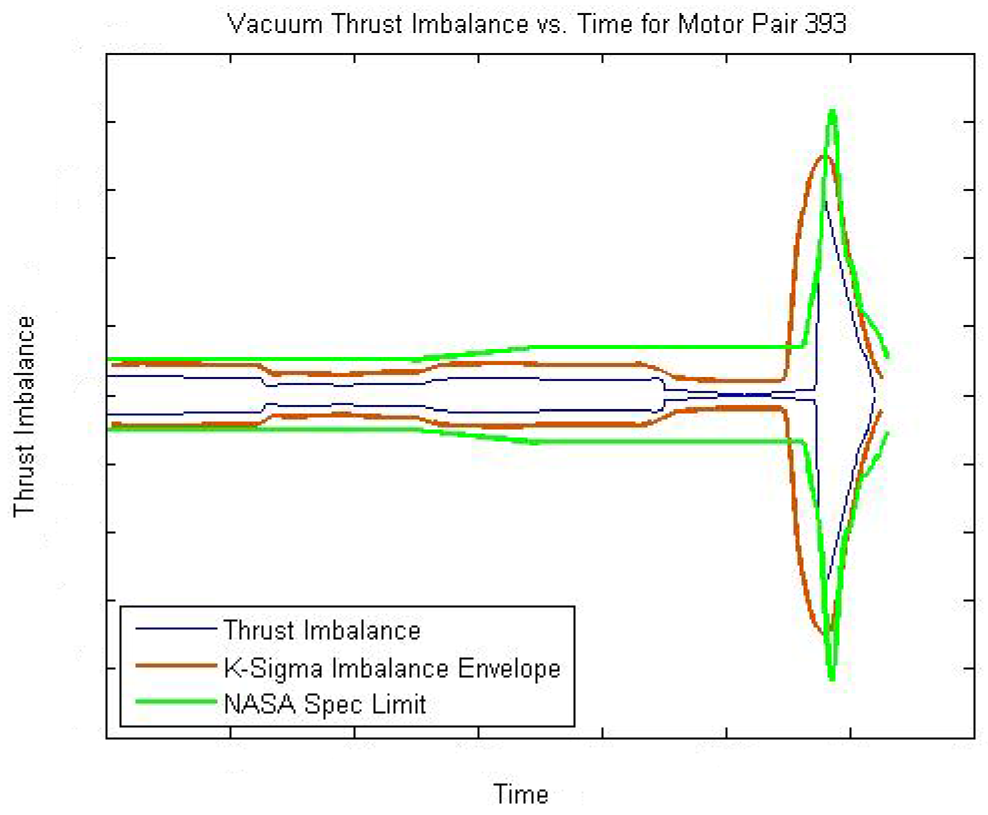
Steady State Thrust Imbalance Envelopes PMBT 40º-90º F (K=3.472)



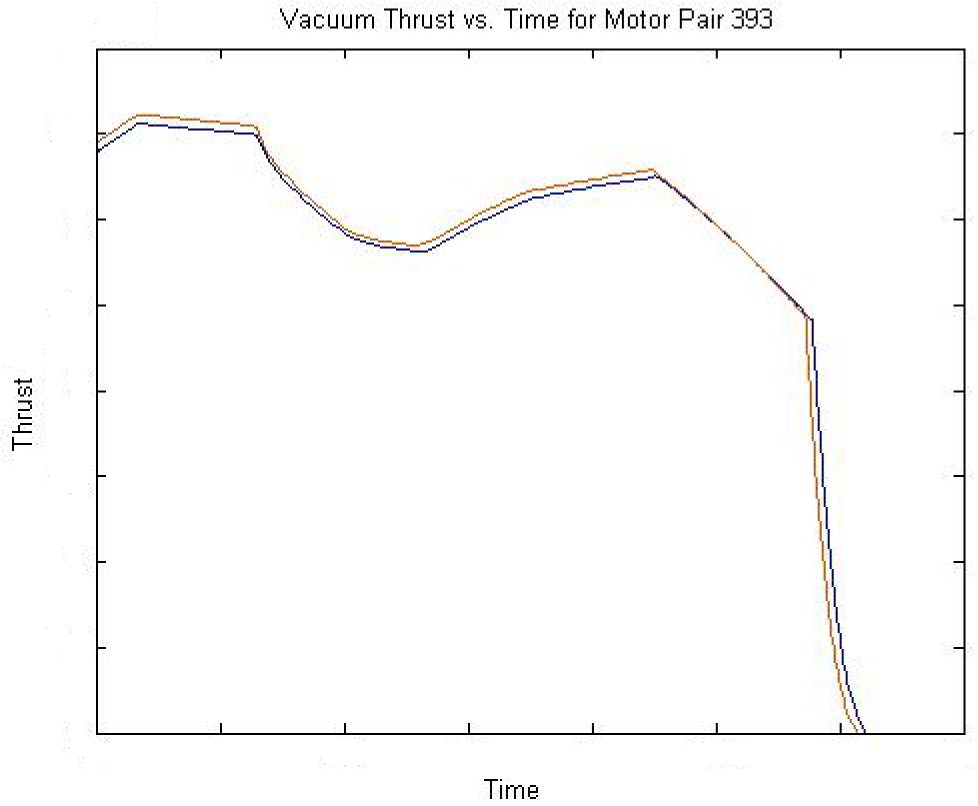
Thrust Time Traces
PMBT 40º-90º F (K=3.472)



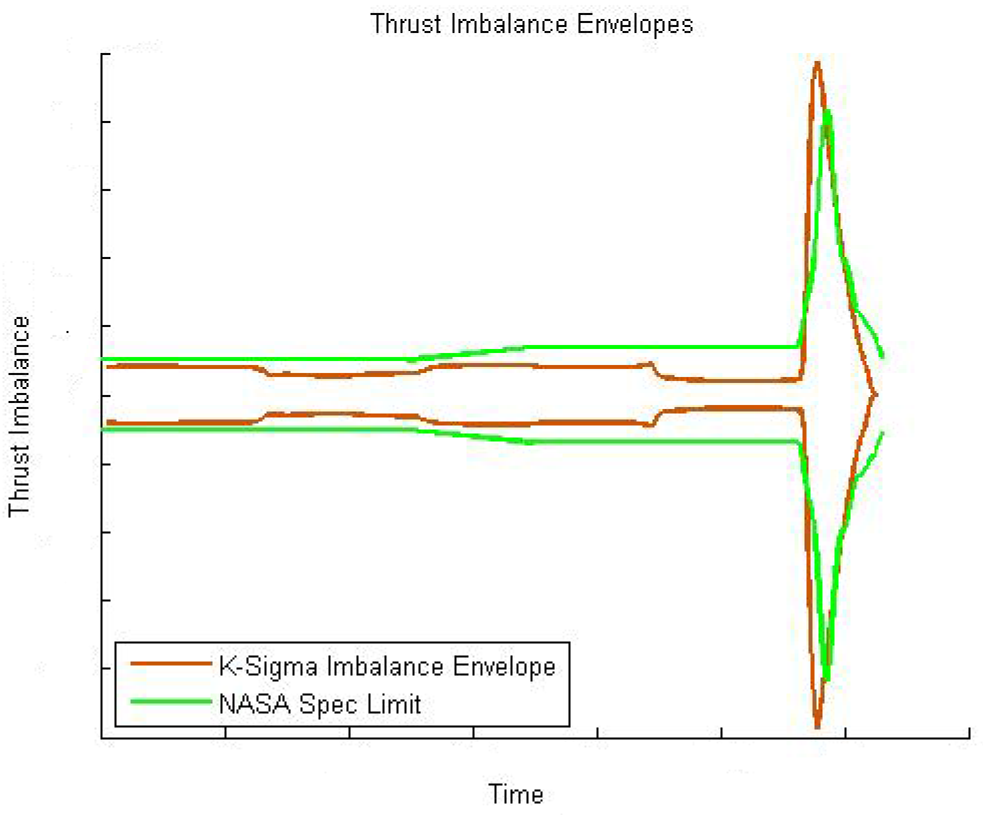
Typical Steady State Thrust Imbalance PMBT 40º-90º F (K=3.472)



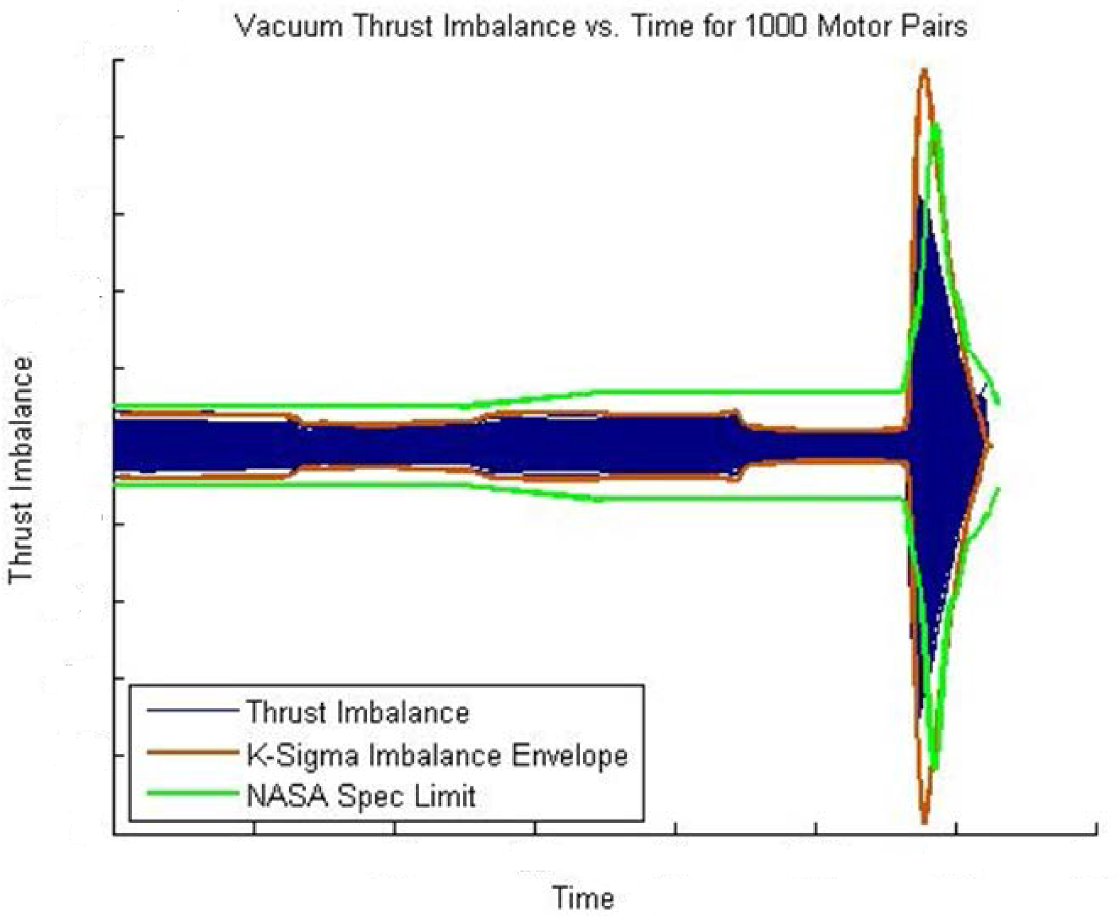
Typical Steady State Thrust Time Traces PMBT 40º-90º F



Steady State Thrust Imbalance Envelopes PMBT 90º F (K=3.472)



Steady State Thrust Imbalance Envelopes PMBT 90º F (K=3.472)



Summary

- Two legacy internal ballistics codes were coupled with a Monte Carlo analysis code to determine the thrust imbalance as a function of time during the ignition transient, steady state and tail-off for the SLS vehicle solid rocket boosters
- A MATLAB shell program was created to manage the input data, execution and graphical results of the analyses
- The predicted values for thrust imbalance versus time obtained from the Monte Carlo predictions agree well with the current NASA design specifications for the SLS boosters