Plan for Compensation of Self-Gravity on ST-7/DRS

Jordan P. Evans
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA 91109
Jordan.P.Evans@jpl.nasa.gov

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Introduction

The ST-7 Disturbance Reduction System will demonstrate drag-free control of a test mass with acceleration disturbances below $3x10^{-14}$ $m/s^2/\sqrt{Hz}$

Constant forces are not important in themselves (provided they are within the dynamic range of the control system)

Differential forces need to be opposed by electrostatic suspension of one test mass

– AND suspension forces have a gradient which couples spacecraft motion to test mass

Force gradients couple spacecraft motion to test mass (aka “stiffness”)

Resulting requirements for DC differential force and gradient are:

– Total differential acceleration between the two test masses due to self-gravity must be $\leq 5x10^{-10}$ m/s^2 in any axis
– DC acceleration gradient due to self-gravity $\leq 4x10^{-8}$ $m/s^2/m$ in any axis of either test mass

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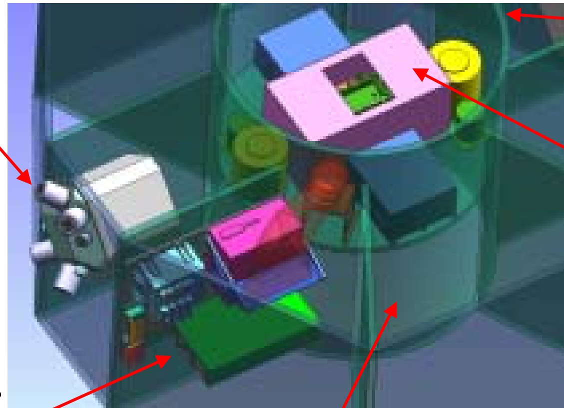
Contributors to Differential Acceleration and Gradient

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

DRS Within LPF



Spacecraft (Transparent)

Thruster Assembly

Sensor Assembly

Electronics Assembly

LISA Technology Package (Not Shown)

DRS Sensor Assembly

Chassis Assembly

Getter Assembly

GRS Control Unit

Caging Pressure Source

Chassis Assembly

Interferometer

Housing

Chassis

Caging Actuator

Vacuum Plenum

Test Mass (not shown)

Masses Throughout the GRS, DRS, and LPF Assemblies Contribute to Self-Gravity

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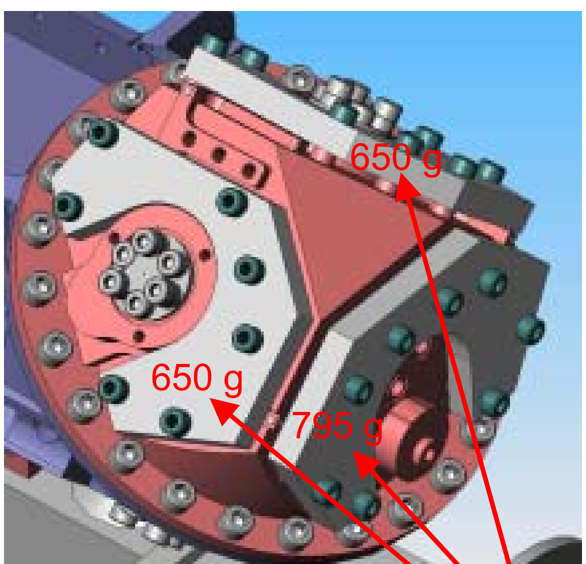
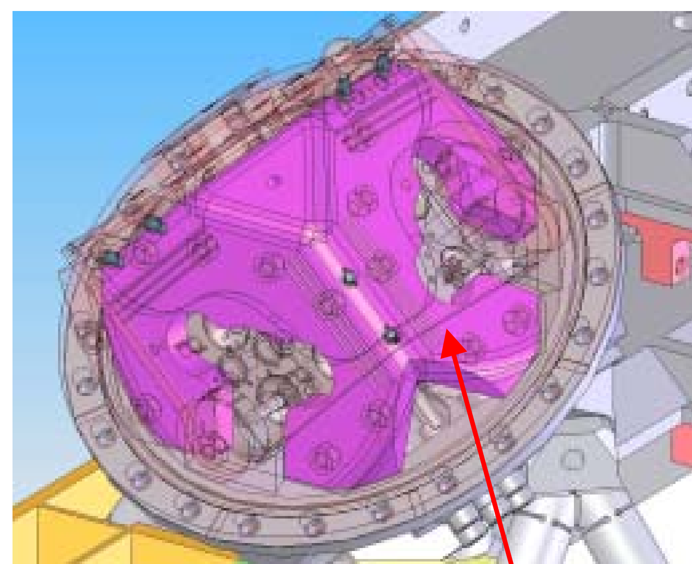
Description of the Trim Masses

Masses used to compensate for the self gravity effects are governed by two primary driving requirements and one schedule constraint

Requirement/Constraint	Implementation
Trim Mass Shall Be Š 1.5 kg Per Side of DRS	Place Trim Masses as close to Test Mass as possible due to $1/R^2$ benefit (results in ~3x mass savings)
Trim Mass Shall Meet the Volume Constraints of the GRS Design	Choose dense, easily-machined material (Tungsten-Copper, ρ = ~16 g/cm^3)
Knowledge of the Detailed Mass Distribution on LPF Will Not Be Available Early Enough	Two-step trimming process 1. Approach compensation w/ internal trim mass prior to GRS closeout 2. Finalize compensation w/ external trim mass requiring physical access late in the I&T flow



2.1 kg_{TOTAL} External "Blanks"



2.3 kg Internal "Blank"

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Planned Self-Gravity Analysis Tools and Associated Error Analysis

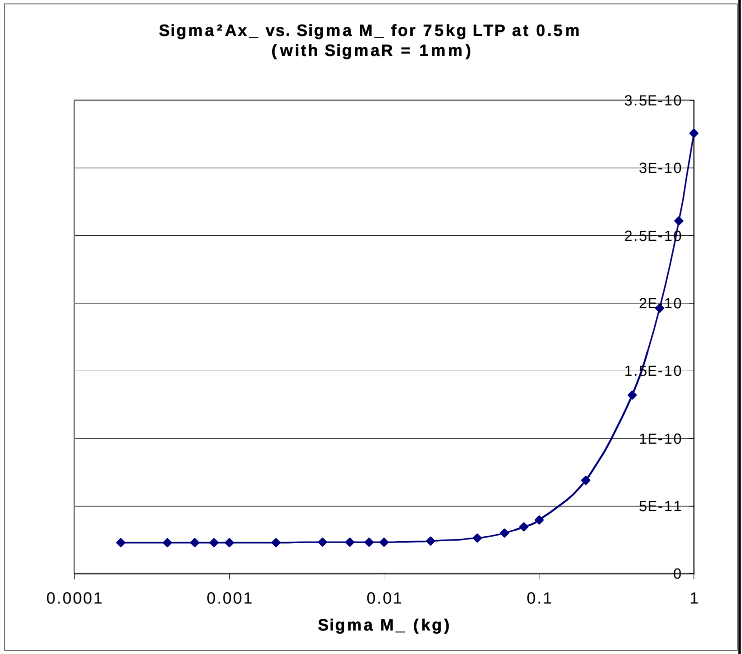
The self-gravity compensation plan utilizes existing models and prediction tools for determining the LTP, LPF S/C, and DRS contributions and for determining the final shape requirements for the trim masses

Usage	Tool Source	Model Source
DRS Self-Contribution	Swales Aerospace Self-Gravity Analysis Tool [3]	JPL Solid Model
S/C Bus Contribution	N/A - Spacecraft Bus will provide forces, torques, and gradients at each of the test mass locations	N/A
LTP Contribution	JPL Matlab routines (not yet published)	Univ. of Trento (LTP Architect) [4]
Trim Mass Determination	Swales Aerospace Self-Gravity Analysis Tool [3]	JPL Solid Model

The graph and requirements table are a representative example of the statistical error analysis results

- For a given mass location error, there is a knee in the curve of mass error beyond which there is no appreciable benefit in overall differential acceleration error
- Mass location error analysis plots follow a similar behavior
- Final plan will include similar requirements for the LPF S/C Bus

Parameter	Requirement (TBR)
Mass Uncertainty of LTP	Š 0.01 kg
Location Uncertainty of LTP	Š 0.001 m



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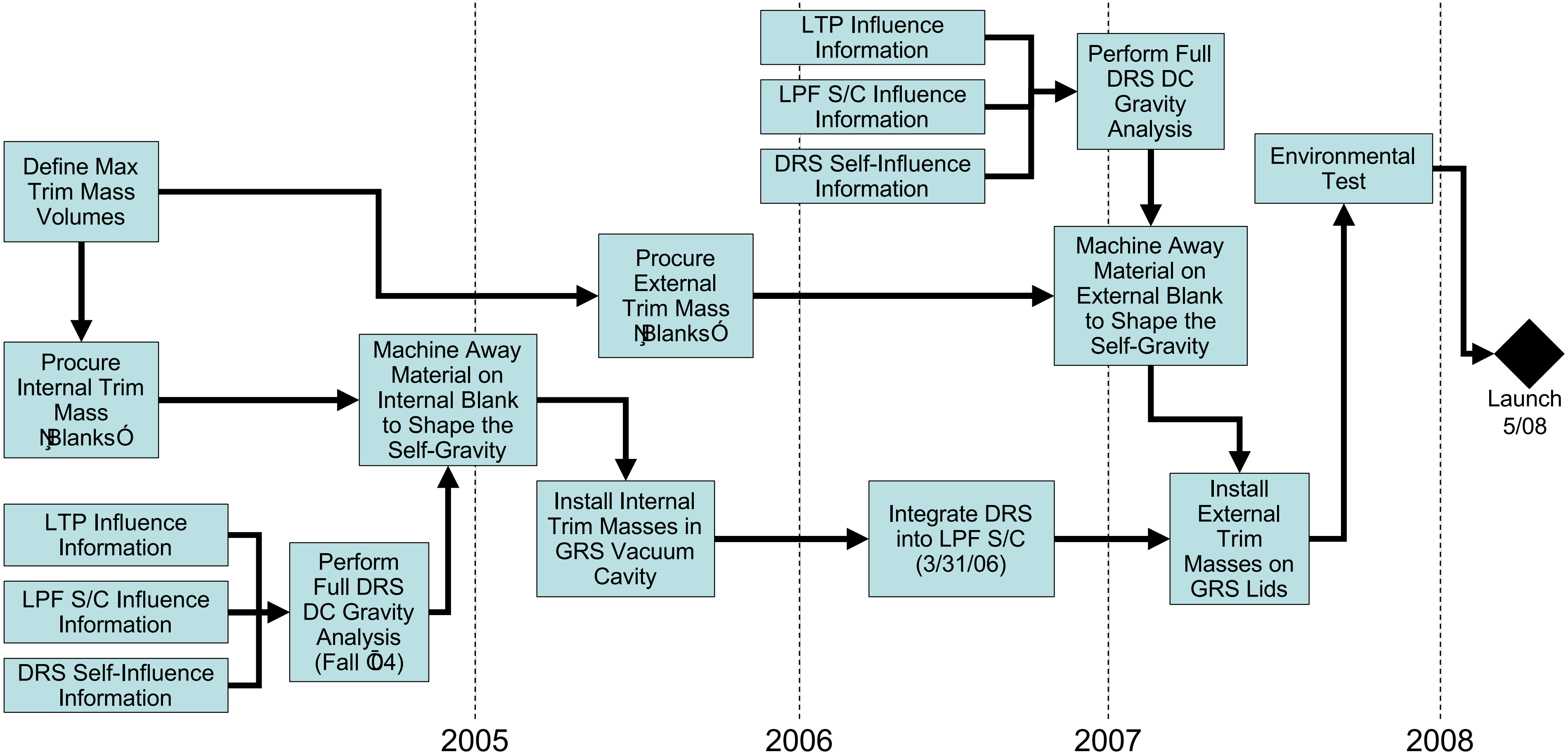
Integration & Test Flow and Relevant Milestones



The I&T flow permits pre-fabrication of the trim mass “blanks” in parallel with DC self-gravity analyses that take advantage of the most current information and mature models available

Final machining can take place within weeks of the actual installation

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Future Plans and References Cited

The final Self-Gravity Compensation Plan for ST-7/DRS is scheduled to be released in October, 2004

Prior to release, there are several activities planned:

- Perform a complete preliminary analysis for forces, torques, and gradients after the DRS CDR (scheduled for August, 2004)
- Release the Trim Mass to Gravitational Reference Sensor (GRS) Interface Control Drawings (ICDs)
- Complete the error analysis and associated requirements for the LPF Spacecraft Bus and the DRS components

References Cited:

- [1] SAI-RPT-570 rev. A, "Preliminary Self-Gravity Analysis of the ST-7/DRS" by William Haile, Swales Aerospace, 10FEB2004
- [2] S2.ASU.RP.2.004, "LISA Pathfinder System Budgets Document" by J. McCall, EADS Astrium Ltd., MAY2004
- [3] SAI-TM-2128, "A Self-Gravity Analysis Tool" by William Haile, Swales Aerospace, 14JUL2003
- [4] LTPA-GCP-UTN-Iss001-Rev0, "LTP Gravitation Control Protocol" by M. Armano, D. Bortoluzzi, S. Vitale, University of Trento, 15MAR2004

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