Propulsion Systems Department

JACOBS
ESSSA Group

TankSIM: A Cryogenic Tank Performance Prediction Program

L. G. Bolshinskiy, A. Hedayat, L. J. Hastings, J. P. Moder, A. R. Schnell, and S. G. Sutherlin

Presenter: Leonid Bolshinskiy

June 2015

Contract NNM12AA41C, Task Order ES.19.05.R22.SSEI.IPR.0000

Agenda

- Introduction
- TankSIM Technical Approuches
- TankSIM Validation
- TankSIM Modeling of Multiphase Mission
- Conclusions

JACOBS ESSSA Group

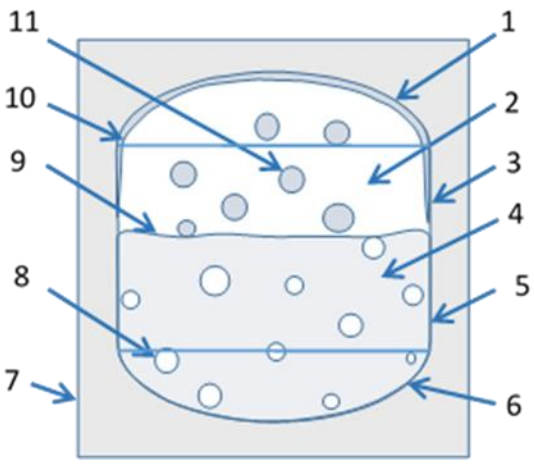
Introduction

Tank System Integrated Model (TankSIM):

- Developed for predicting the behavior of cryogenic liquids inside propellant tanks under various environmental and operating conditions.
- Provides a multi-node analysis of pressurization, ullage venting and thermodynamic venting systems (TVS) pressure control using axial jet or spray bar TVS.
- Allows user to combine several different phases for predicting the liquid behavior for the entire flight mission time line or part of it.
- Is a NASA in-house code, based on FORTRAN 90 – 95 and Intel Visual FORTRAN compiler, but can be used on any other platform (Unix-Linux, Compaq Visual FORTRAN, etc.). The last Version 7, released on December 2014, included detailed User's Manual.
- Includes the use of several RefPROP subroutines for calculating fluid properties.

TankSIM Technical Approuches

1 TankSIM Nodes



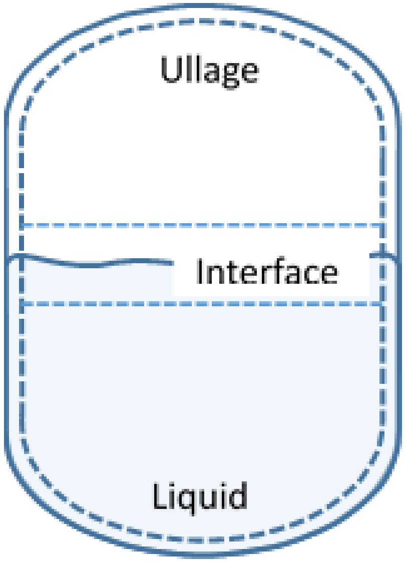
TankSIM Nodes

1. Ullage wall - upper head part (upper dome) of the tank wall interfaced to the ullage;
2. Ullage;
3. Ullage wall - cylindrical part of the tank wall interfaced to the ullage;
4. Bulk liquid;
5. Liquid wall - cylindrical part of the tank wall interfaced to the liquid;
6. Liquid wall - bottom head part (lower dome) of the tank wall interfaced to the liquid;
7. Environment;
8. Bubbles in bulk liquid
9. Ullage - liquid interface;
10. Wall liquid - liquid film on the ullage tank wall;
11. Droplets in ullage.

JACOBS
ESSSA Group

TankSIM Technical Approuches (contd.)

2 Control Volume definitions

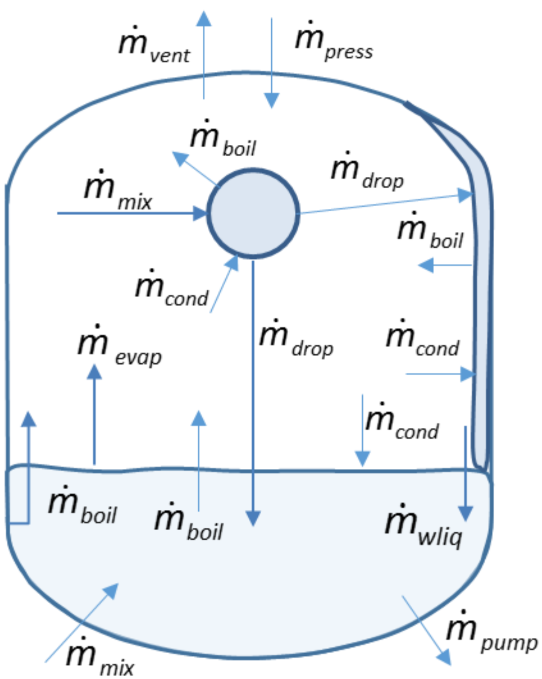


Control Volumes

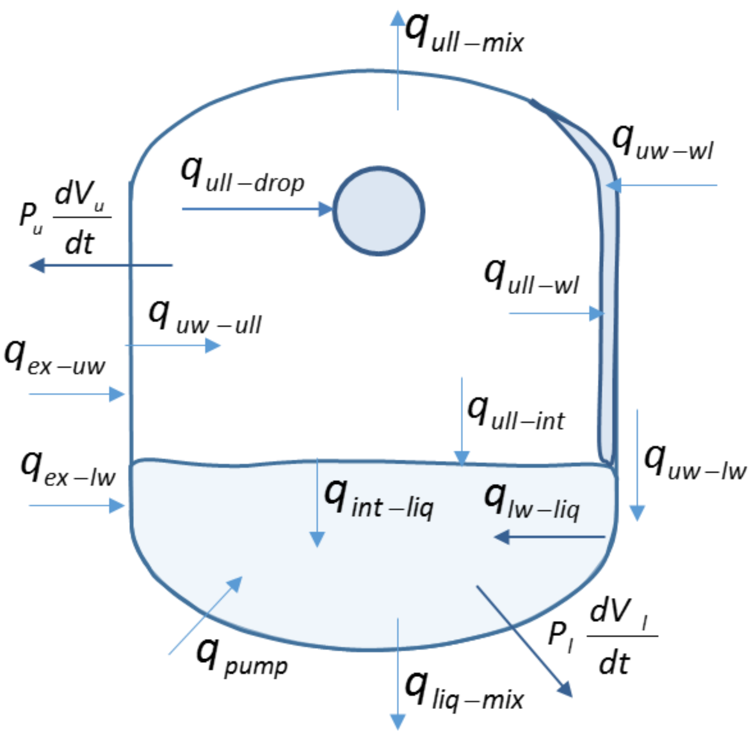
1. Ullage - mixture of propellant vapors and incondensable pressurization gas
2. Liquid - liquid propellant remaining in the tank
3. Ullage-liquid interface - infinitely thin layer at propellant saturation conditions containing no mass and used for description of the heat transfer between liquid and ullage and evaporation-condensation processes at the interface.

TankSIM Technical Approuches (contd.)

3 Mass and Energy Balances



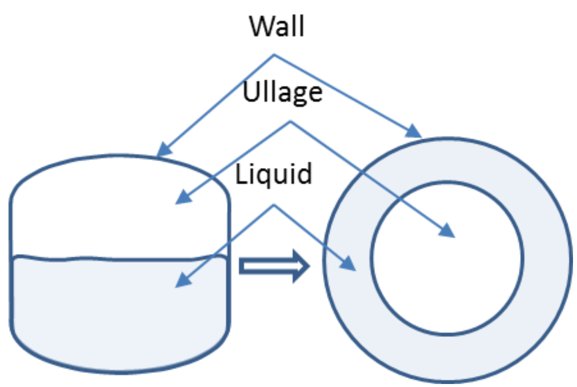
Mass Balance Schematic



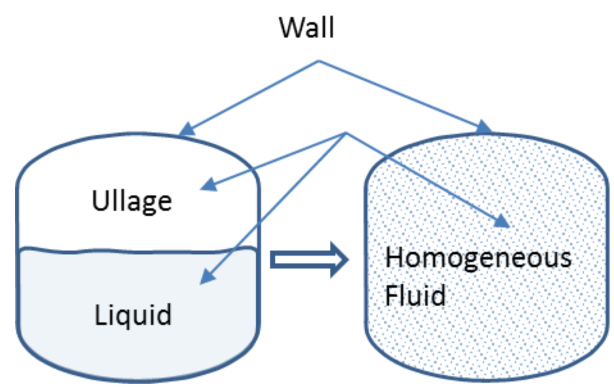
Energy Balance Schematic

TankSIM Technical Approuches (contd.)

4 Tank Geometry Transformation for the Micro-gravity Cases



Non-mixing Cases

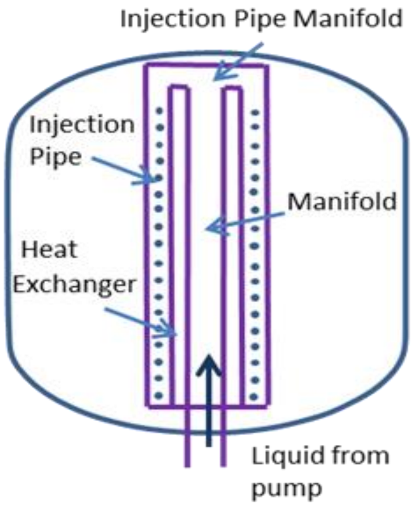


Mixing Cases

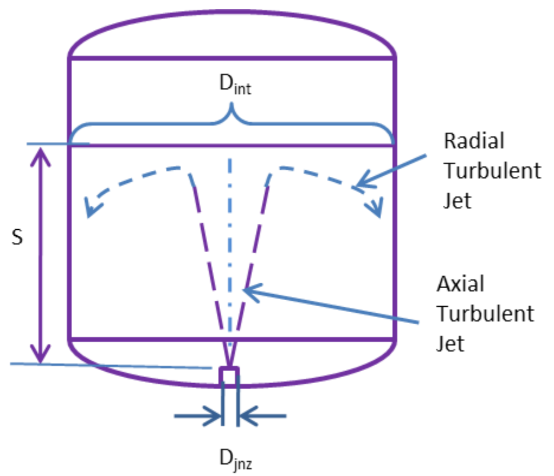
Volume of outer sphere is equal to the tank volume, volume of internal sphere is equal to the ullage volume, and volume of the liquid layer is equal to the bulk liquid volume. The heat transfer to the ullage is calculated using conduction shape factor for the "sphere in sphere" shape.

The model with the homogeneous fluid in the total tank volume was accepted. Thermodynamic properties (density, thermal conductivity coefficient, specific heat capacity and other) calculated as mass weighted average quantities of liquid, vapor and incondensable gas.

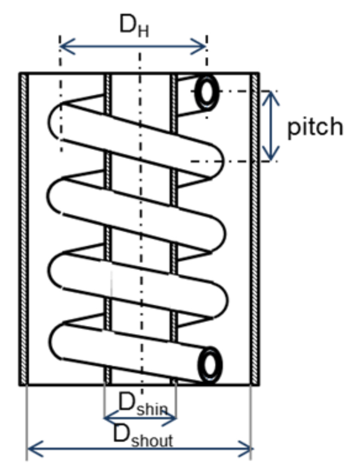
4 Spray Bar and Axial Jet TVS



Spray Bar

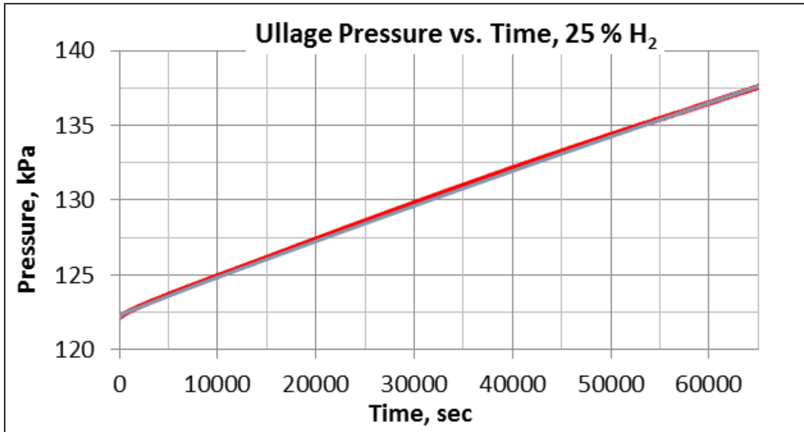


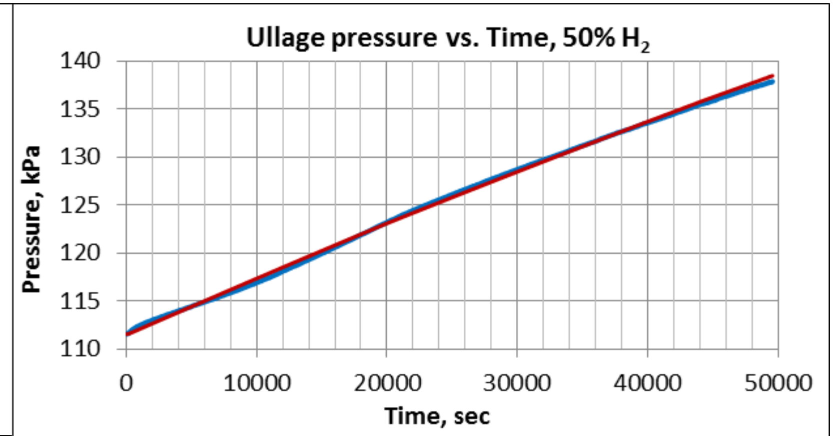
Axial Jet

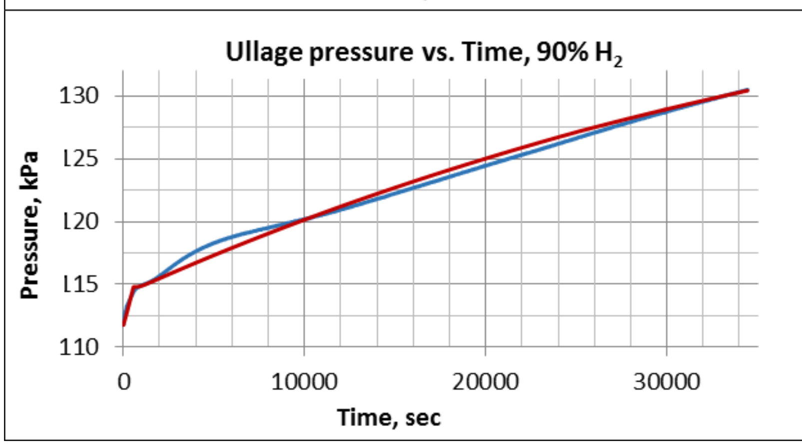


Heat Exchanger for Axial Jet

1 MHTB Hydrogen Self-Pressurization





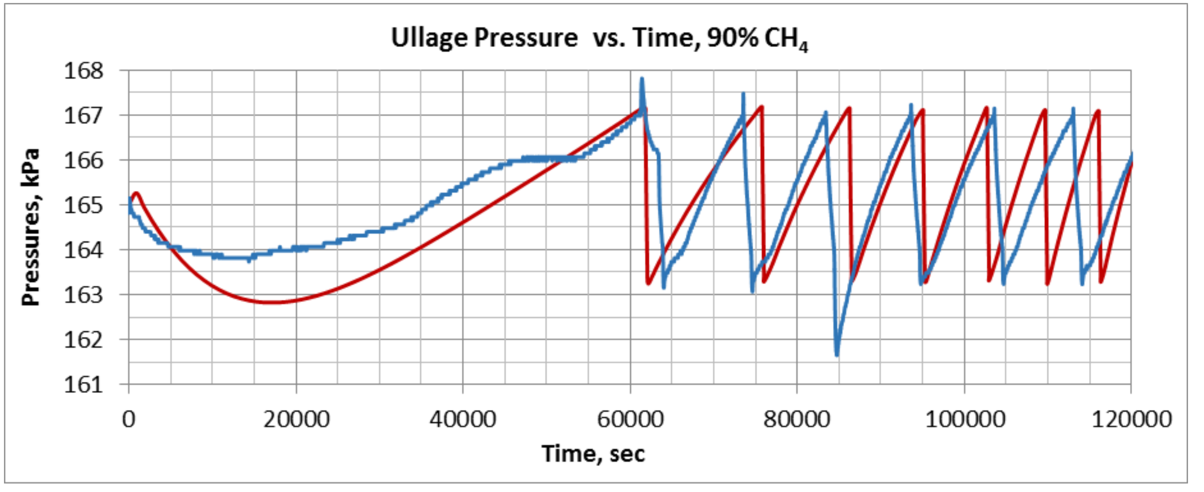


The MHTB 5083 cylindrical aluminum tank with a height of 3.05 m, a diameter of 3.05 m, and 1:2 elliptical domes. Internal volume of 18.09 m^3.

The red line corresponds to the TankSIM data and the blue line corresponds to the test data.

TankSIM Validation (contd.)

2 MHTB Methane Spray Bar TVS



Results for methane test with the spray bar TVS working. The initial ullage consist of hydrogen vapor with pressure 60.15 kPa and helium with pressure 104.86 kPa.

JACOBS ESSSA Group

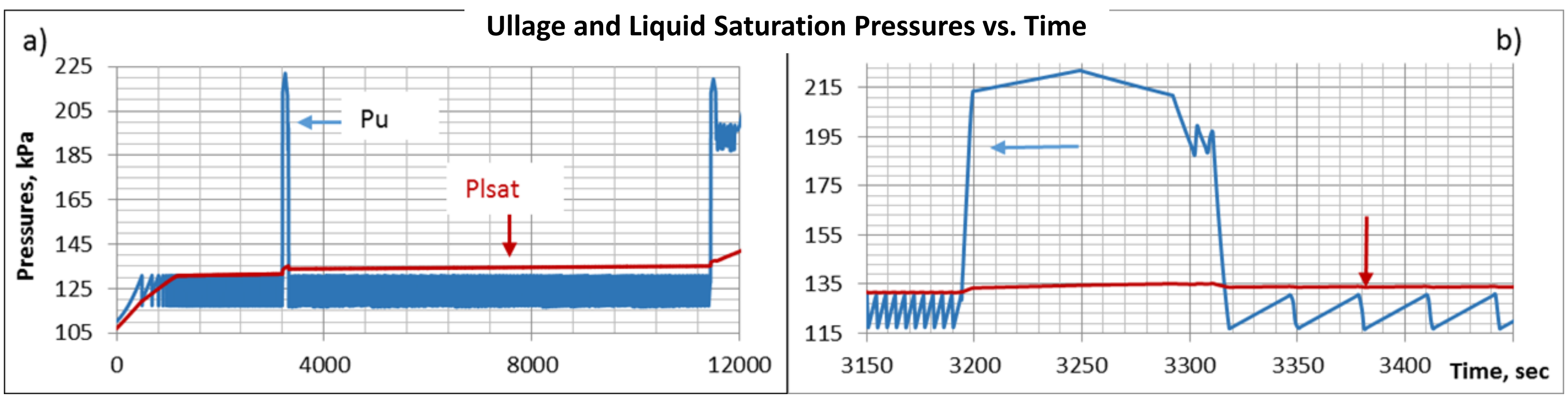
TankSIM Modeling of Multiphase Mission

Multiphase Mission Timeline

Aluminum tank with 5 m diameter, 5 m height and 74 m^3 volume. Working fluid – hydrogen, 90 % fill level. The total mission time is 12000 sec. The case a) represents the full mission and case b) – detailed segment around the fist firing.

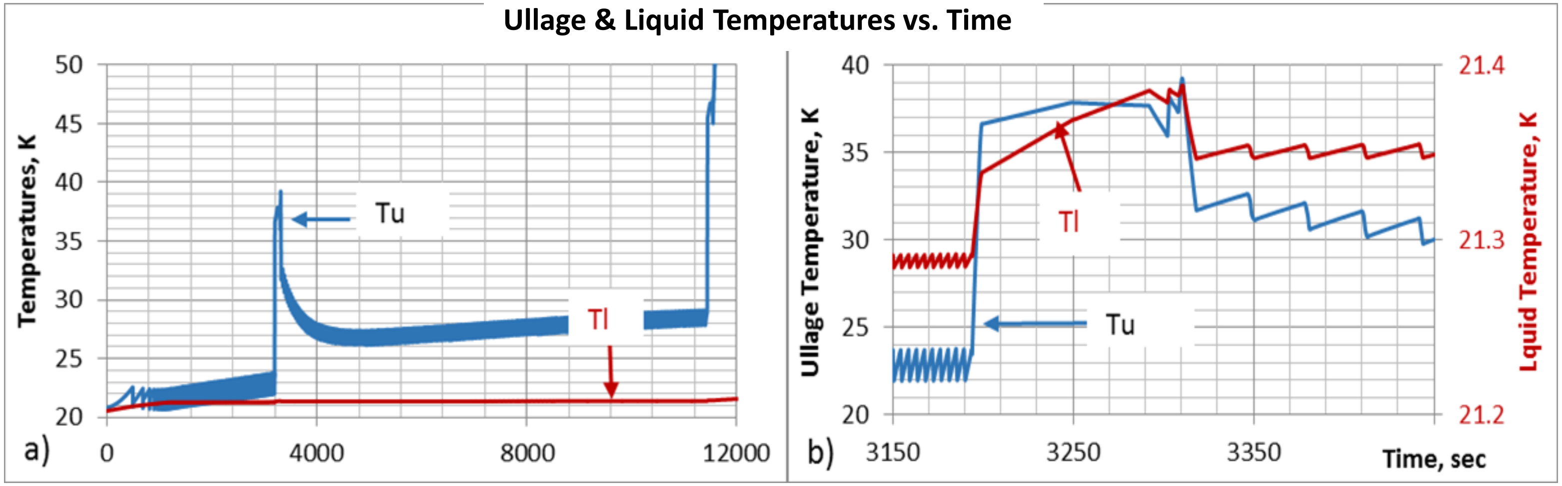
Phase	Self-Press 1	Self-Press 2	Pre-Press 1	Chill-Down 1	Firing 1	Self-Press 3	Pre-Press 2	Chill-Down 2	Firing 2
Duration, sec	494	2700	55	43	19	8100	55	43	491
Acceleration, g	3.3	0.003	0.003	0.003	0.19	0.003	0.003	0.003	0.19
Heat Loads, kW	44.5	30	30	30	30	11.4	11.4	11.4	11.4

Mission Timeline



JACOBS ESSSA Group

TankSIM Modeling of Multiphase Mission (contd.)



JACOBS
ESSSA Group

Conclusions

Advantages of the TankSIM

- High program flexibility for tank shapes, working fluids and using non-condensable pressurization gases
- Ability to model the full mission with set of phases, which can be used in different sequences.
- Ability to add new phases as required.
- Fast computing with relatively high precision

The TankSIM Planned Improvements

- Implementation of the new correlation equations for tank wall-ullage, tank wall-liquid and liquid-ullage heat transfer under normal and low (micro) gravity depending on tank geometry - heads ratio, barrel part length and fill level.
- Adjustment of calculations of the ullage-liquid and tank wall-ullage interface areas for the micro-gravity depending of Bond number, fill level, and shape of tank.

Conclusions (contd.)

- Replacement of the non-settled liquid heat transfer calculations during mixing from current model with the gas ullage and set of liquid spheres.
- Validation of the TankSIM code using all available NASA and other test data.
- Development of the Graphical User Interface (GUI).

The End

Questions ?