A REVIEW FOR DEVELOPING THERMODYNAMIC MODEL OF COMS CPS

Jongwon Chae, Cho Young Han, and Koon Ho Yang

KARI, firstbel@kari.re.kr

COMS (Communication, Ocean and Meteorological Satellite) is a geosynchronous satellite and has been developing by KARI and Astrium for Ka-band communication, ocean observation and meteorological observation. COMS Chemical Propulsion System (CPS) uses a bipropellant propulsion subsystem, which is applied for transferring COMS from GTO to GEO (mission orbit) and implementing station-keeping manoeuvres. In this paper COMS CPS is briefly introduced for understanding. A few of mathematical thermodynamic modelings of bipropellant propulsion system in literatures are reviewed and authors has studied those models for developing a computer program, which predicts variations of thermodynamic properties such as temperature and pressure histories in the helium pressurant tank, MMH propellant tank and NTO propellant tank during LAE firing and on-orbit manoeuvrings. The CPS thermodynamic model may be used to compute pressurant and propellant masses and to size tank volumes.

KEY WORDS: COMS, CPS, Thermodynamic Model

1. INTRODUCTION

1.1 COMS

COMS (Communication, Ocean and Meteorological Satellite) is a geosynchronous satellite and has been developing by KARI and Astrium for Ka-band communication, ocean observation and meteorological observation. Overall configuration of COMS is shown in Fig 1.

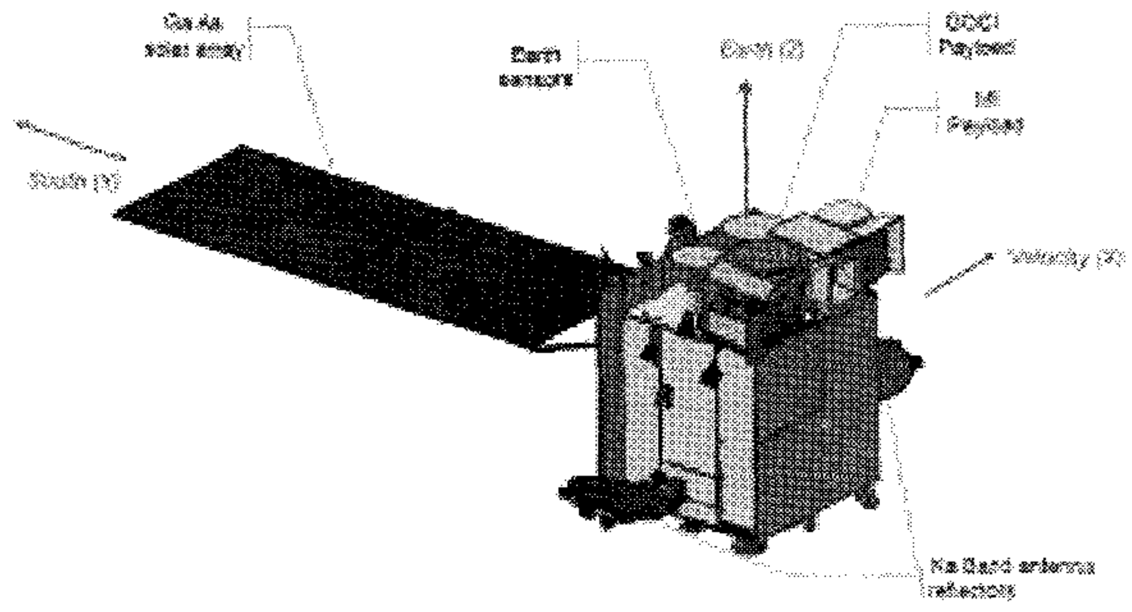

Figure 1. COMS Overall Configuration.

1.2 COMS Chemical Propulsion Subsystem

COMS CPS consists of one helium pressurant tank, two propellant tanks, series redundant pressure regulator, four non-return valves, two filters, two orifices, fourteen reaction control thrusters (station keeping on orbit), one liquid apogee engine (orbit raising), many normally open pyro-valves and normally closed pyro-valves, five pressure transducers, two latch valves (separating two branches), test ports, fill/drain valves and complex pipeline networks.

It uses MMH as fuel, NTO (or MON-3) as oxidizer and helium as pressurant.

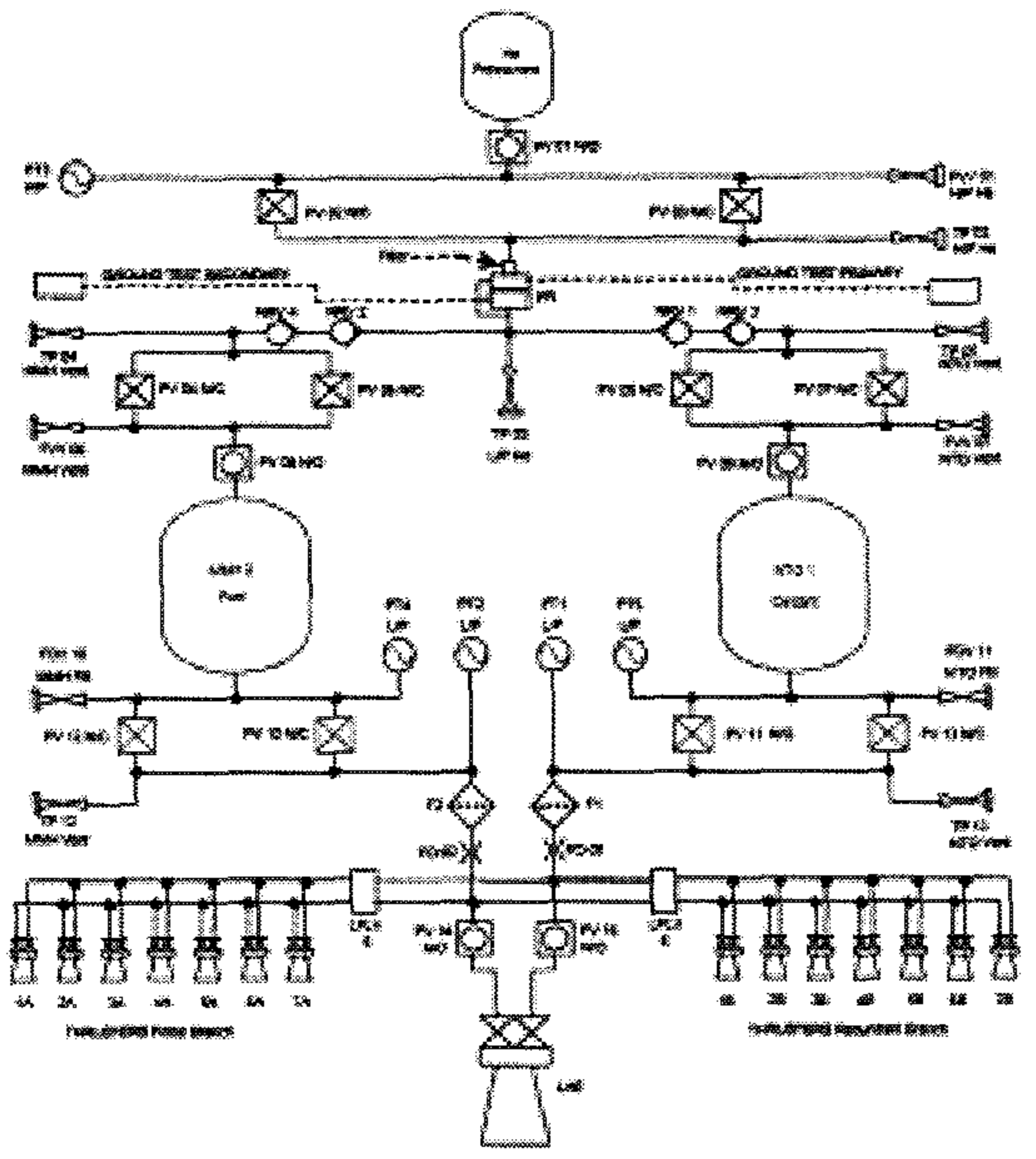

Figure 2. COMS CPS Schematic.

2. HISTORICAL REVIEWS

F. Bizjak, et al presented a performance analysis method of the stored gas pressurization systems for propellant transfer. Theoretical equations are developed from fundamental thermodynamic and heat transfer concepts;

Between the pressurant tank wall and the control volume in which the pressurant contains, and

Between propellant tank wall and the moving control volume in which mixtures of propellant vapor and pressurant contain. This paper is seldom referred in literature but it has pointed out analytic derivations that can be used for different pressurant/propellants combination and comparable gas pressurization systems [1].

The general equations for thermodynamics of pressure vessel blowdown presented in well-known NASA document, the design guide for pressurized gas systems. These equations are applied for blowdown process of pressurant tank [2].

G. F. Pasley developed a set of equations from the energy conservation principle to the pressurant tank and introduced the determination of the heat-transfer coefficient is the key to the development of a general set of equations. It presented a relationship derived from the results of "experiments on free-convection heat transfer from the surface of a sphere to a fluid filling the interior." The equation is mainly referred in many literatures. The predicted results are compared with flight and ground test data [3, 4].

L. D. Wing described the thermal effects such as Joule-Thompson effect during pressurization of vehicle gas tanks from reservoir tanks [5]. The Joule-Thompson (or Joule-Kelvin) effect occurs during blowdown process of LAE firing in which the pressurant with high pressure is drawn from the pressurant tank to maintain the propellant tank pressure at set points, relatively low pressure. The Joule-Thompson effect is a phenomenon of real gases which (in certain temperature and pressure regions) causes the gas temperature to increase or decrease with decrease in pressure for a throttled process. The value of Joule-Thompson coefficient for Helium in the interested range (commonly from 210 bar to 17 bar) is negative so that the temperature of the regulated gas through a pressure regulator increases.

H. C. Hearn wrote a lot of important papers about bipropellant propulsion systems. He concluded helium as a pressurant probably mandatory through the feasibility study in which it compares the abilities of pressurant nitrogen and helium [6]. He developed a computer model which incorporated thruster characteristics and various pressurization/feed system variables, including pressurant solubility [7].

P. N. Estey et al [8] presented a thermodynamic model to predict a propellant tank pressure history. The model described an analysis of the time response of a propellant supply system operating in the blowdown mode. This paper had a focus on the propellant tank, especially in the moving control volume of propellant tank, which are ullage phenomena; mass and heat transfer between vapor/gas, film layer separating the liquid and vapor phase, liquid and tank wall. He applied the principles of mass and energy conservation in result of the set of ordinary, coupled, nonlinear differential equations for the thermodynamic state variables, which is integrated as an initial value problem using state space method. He also proposed a relationship that an area of the ullage/wall interface (which does not include the film layer area) is correlated to the gas/vapor volume and non-dimensionalized by the tank volume for a spherical tank. This equation is used in a few of papers for a calculational convenience.

Almost same times H. C. Hearn studied thermodynamic considerations in bipropellant blowdown systems and concluded that an exact knowledge of the actual physical processes (i.e., evaporation or condensation) is not required [9] but the mass of propellant in ullage is needed for the estimation of propellant budget calculation so that it is required to calculate its mass with an range.

T-P. Yeh developed a set of Monte Carlo-Type computer programs to analytically predict the capability of a spacecraft bipropellant propulsion system [10]. He gave a brief description of the development of the system operation and performance model and optimum propellant loading model. It is not useful for developing a thermodynamic model due to its simple description.

R. W. Devey presented the salient features of the propulsion subsystem of the Olympus satellite. The COMS CPS followed all the same design of the Olympus satellite' CPS except the numbers of pressurant tank and thrusters [11].

A. Ricciardi and E. Pieragostini wrote a paper that describes the theory and the model used to develop a computer program [12]. This program is to predict the performance and the thermodynamic conditions of a bipropellant propulsion system during its life time. The bipropellant propulsion system consists of mainly LAE firing period and station keeping period after acquisition of GEO orbit. Usually LAE firing is approximated by adiabatic process due to relatively short period and big consumption of propellant and pressurant. Station keeping periods are modelled by isothermal process due to the long non-operation and small use of propellants. It was mainly developed for a unified bipropellant propulsion system (UBPS) like the geostationary satellites (i.e., Italsat, Olympus etc.). Applying the equations of mass and energy conservation principles to the pressurant tank and the propellant tanks, the program is capable to predict the thermodynamic conditions (i.e., temperatures and pressures in the pressurant tank and the propellant tanks) with taking into account propellant evaporation, heat exchange between the gas/vapor mixture and the tank's walls and pressurant solubility in each propellant tank. This paper did not present a method of solving the set of equations and the results for comparison with test data.

R. P. Prickett et al had a focus on developing an accurate modelling of a hydrazine reaction control subsystem (RCS) for accurate orbital life predictions [13]. This paper will be a reference for the station keeping modelling.

D. M. Gibbon et al developed a way of simulating pressures inside a spacecraft propellant tank. This involved the use of a scaled-down propellant tank filled with propellant, MON-3 and helium at various fill levels. It presented a range from 0 % helium solubility to 100 % theoretical helium solubility in the temperature-pressure diagram and compared the test points with predictions [14].

L. W. Hobbs summarized the performance verification of the Eurostar propulsion subsystem [15]. This paper is useful for understanding the COMS CPS followed the same design of Eurostar except the number of tanks. Although it gave full explanation about the software and analysis logic structure, it hinted how to correlate many independent separate models (thermal models, pressure drop model, on-station model, thruster box model, propellant tank capacity model, pressurant requirements model, pressurisation time model, etc.) with system geometry and batch of components. It presented the results of the cold flow test and others.

D. Haeseler et al presented the flow scheme and modelization of the feedline system of HERMES propulsion subsystem [16]. It is a good starting point for a pressure drop modeling of pipe network analysis.

T. P. Yeh illustrated subsystem performance by comparing the flight data to the analytical models to predict the remaining propellant for INSAT-1B [17]. Especially the comparison of helium tank pressure of computer model to INSAT-1B flight data may be helpful for validation of COMS CPS computer program.

G. P. Purohit et al presented a method of helium solubiltiy control prior to propellant loading and dealt with thermodynamics of pressurized propellant tanks with specific propellant tank data [18]. It also represented the pressure expansion coefficient and temperature expansion coefficient for the propellant. The expansion (or stretch) coefficient is significant for estimating the propellant budget and also necessary to the pressurant budget.

D. Haeseler and M. Popp presented a computer program that simulates the performance of a pressurized bipropellant propulsion system using storable propellants [19]. It was be used for the analysis of design and off-design operations of the Ariane 5 upper stage EPS and the Hermes propulsion subsystem. This concept can be applied to satellite propulsion systems. Unfortunately it did not present a set of governing equation in detail but it would be a good reference for developing and validating the computer program.

R. W. Devey presented the post launch assessment of the operation and performance of the Olympus CPS with telemetry data and orbit parameters [20]. This paper may serve as reference for validation.

C. J. G. Dixon and J. B. Marshall developed the models under the Olympus and Eurostar programmes [21]. The models can be applied to similar spacecraft. The authors simply explained the models without the set of governing equations. The reproducibility of the original page is poor for diagrams so that many diagrams are useless.

V. Shankar et al developed the computer program based on the works of A. Ricciardi and E. Pieragostini [12], applied to INSAT-II unified bipropellant propulsion system and presented the results of computation. Since this paper had been published without author's corrections, it needs to pay attention to read it and to derive all the equations used in the computer program. This paper is worth for INSAT-II component data. Those data give clues how to implement them in the computer program but still there are not sufficient data to complete the models.

G. P. Purohit wrote a remarkable paper for modeling of the processes in the pressurant tank [22]. This paper may be a good reference for pressurant tank modeling.

H. C. Hearn developed the simplified and accurate models for spacecraft propulsion systems and validated them through various spacecraft programs [23].

3. CONCLUSTION

So far many papers are briefly reviewed for developing thermodynamic models of COMS CPS. The authors has already derived all the governing equations for the thermodynamic models followed A. Ricciardi and E. Pieragostini and has built an computer program. Now the authors are attempting to validate the computer code through flight data. COMS CPS flight data will be very significant for the computer program with respect to correlation and validation.

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