SSOS demo proposal
PHM of spacecraft propulsion systems during rendezvous operations

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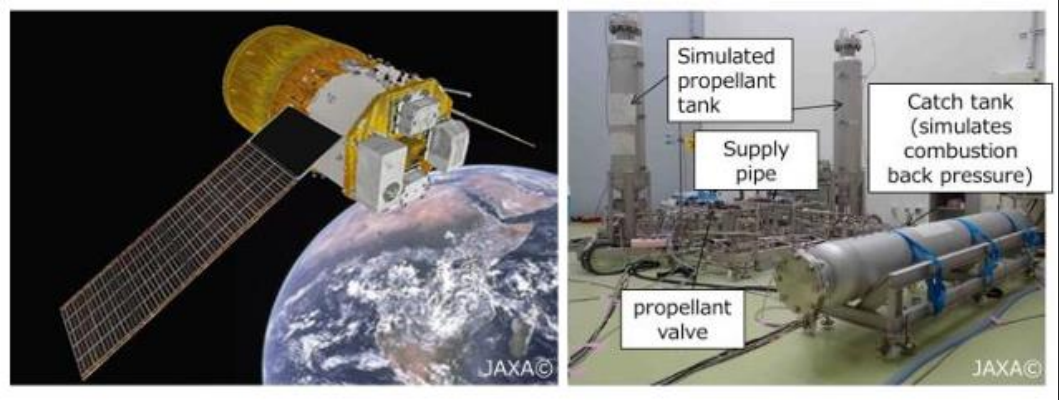
Objectives

- Making demos of PHM（Prognostics and Health Management） of spacecraft propulsion systems during rendezvous operations using SSOS
- Launching open-platform in PHM development using SSOS

Demo scenario and dataset

Demo scenario

- Diagnosing normal, bubble anomalies, solenoid valve faults, and unknown abnormal cases of spacecraft propulsion system



(Tominaga 2023)

Dataset

- Data generated by a simulator for a simplified propulsion system developed with the cooperation of JAXA

*1 Tominaga, K., Daimon, Y., Toyama, M., Adachi, K., Tsutsumi, S., Omata, N., & Nagata, T.
Dataset generation based on 1D-CAE modeling for fault diagnostics in a spacecraft propulsion system.
4th Asia Pacific Conference of the Prognostics and Health Management,Tokyo, Japan, September 11 – 14, 2023, DC01-01.
https://papers.phmsociety.org/index.php/phmap/article/view/3784
https://phmap.jp/program-data/

Schematic of propulsion system

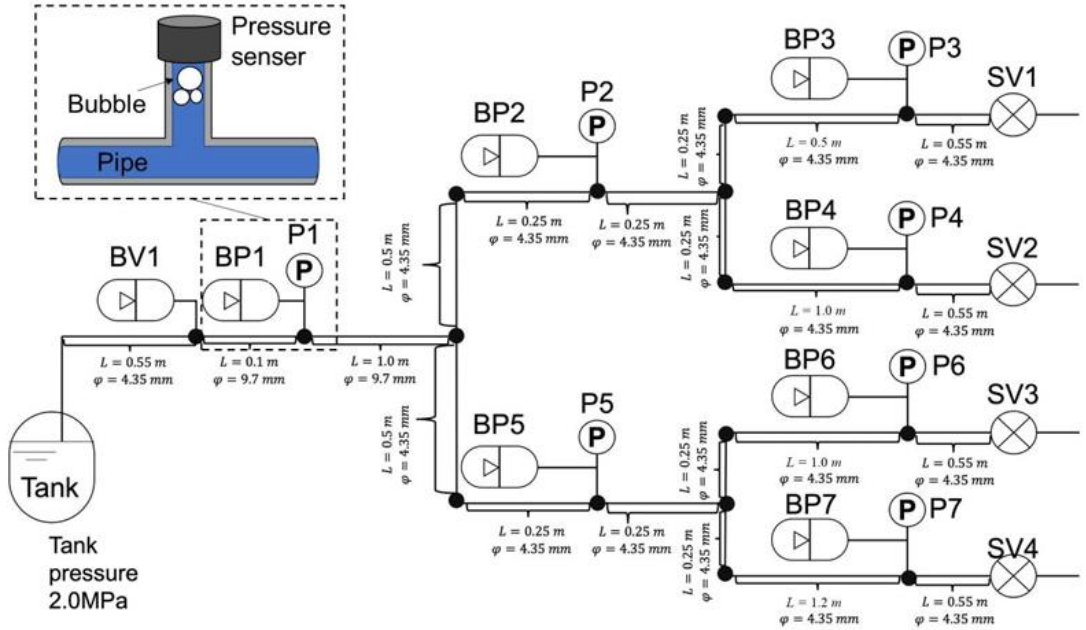


Figure 2. Schematic of propulsion system model.

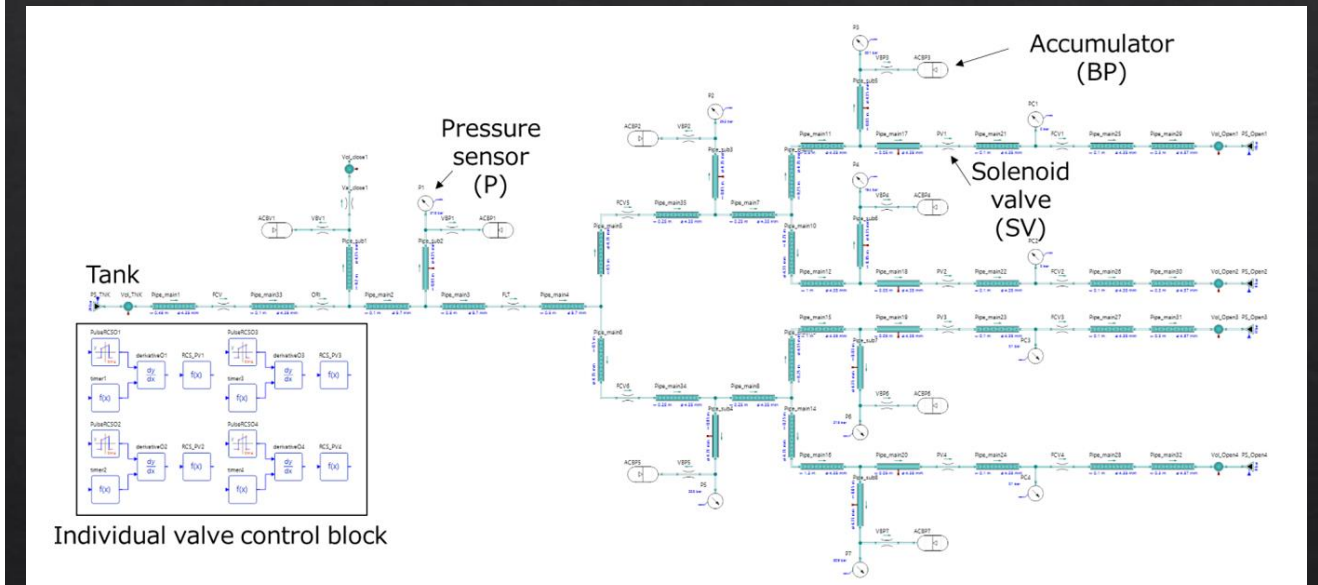


Figure 3. Propulsion system model configuration in 1D-CAE software.

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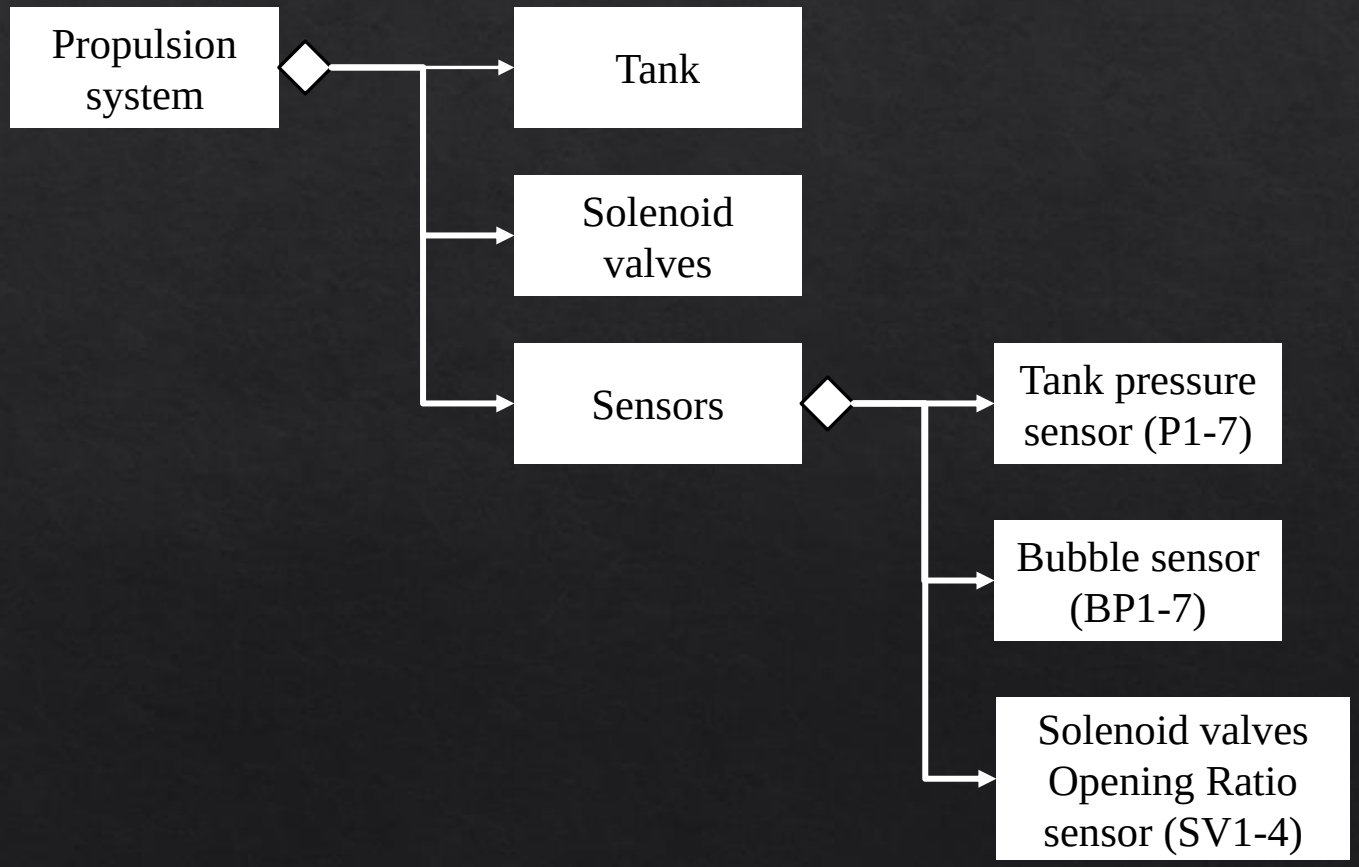
Block diagram of propulsion system



Mechanism of propulsion system

Pressurizing water to 2 MPa

Discharging through four solenoid valves (SV1 – SV4)

Opening and closing the solenoid valves

Water hammer followed by acoustic modes

Pressure fluctuation

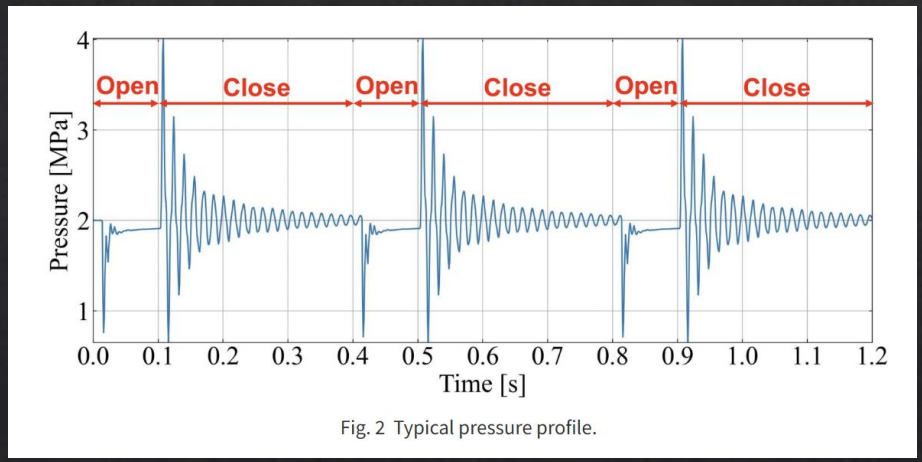


Fig. 2 Typical pressure profile.

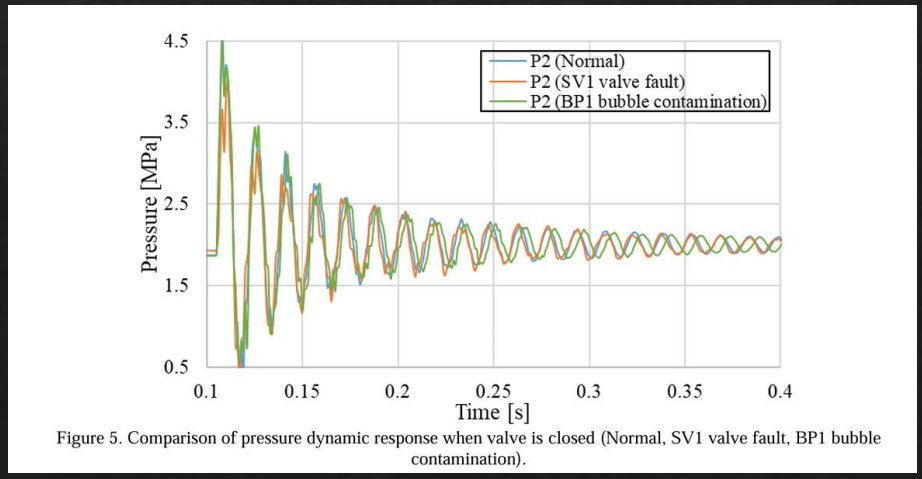


Figure 5. Comparison of pressure dynamic response when valve is closed (Normal, SV1 valve fault, BP1 bubble contamination).

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Anomaly cases

- Bubble anomaly
  This occasionally occur in spacecraft pipes during operation, where air bubbles alter the speed of sound and cause subtle pressure fluctuations.

- Solenoid valve faults
  This is a major failure mode in spacecraft propulsion systems, requiring identification of the failed solenoid valves and their opening ratios.

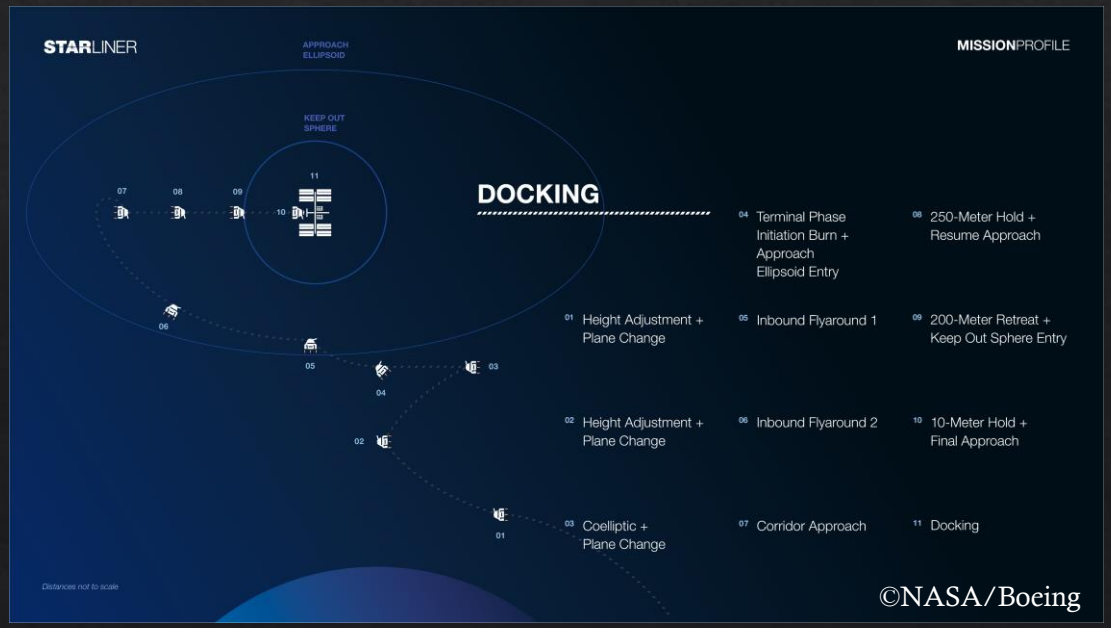
- Unknown anomaly
  During practical operations, unforeseen and unknown anomalies may occur. It is essential to distinguish these from known anomalies and faults, as some unknown issues are present in the test data.

※Individual differences in solenoid valve operation cause variations in propulsion system data, leading to unique characteristics for each spacecraft. Four spacecraft (No.1 to 4) are considered in this case.
No.1 to No.3, are included in the training data, but test data is composed of the results for No.1 and No.4.

Tasks of the demo

- Diagnosing the conditions of propulsion system during rendezvous operations
- Detecting symptoms of anomalies with trained models during rendezvous operations
- Detecting anomalies with trained models during rendezvous operations

Example of Flight Profile during rendezvous (Starliner CFT)



Example of telemetry data

Case#	Spacecraft#	Condition	Solenoid valves Opening Ratio /%				Bubble							
			SV1	SV2	SV3	SV4	BP1	BP2	BP3	BP4	BP5	BP6	BP7	BV1
1	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
2	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
3	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
4	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
5	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
6	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
7	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
8	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
9	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
10	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
11	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
12	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
13	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
14	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
15	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
16	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
17	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
18	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
19	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
20	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
21	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
22	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No
23	1	Normal	100	100	100	100	No	No	No	No	No	No	No	No

106	1	Fault	0	100	100	100	No	No	No	No	No	No	No	No
107	1	Fault	25	100	100	100	No	No	No	No	No	No	No	No
108	1	Fault	50	100	100	100	No	No	No	No	No	No	No	No
109	1	Fault	75	100	100	100	No	No	No	No	No	No	No	No
110	1	Fault	100	0	100	100	No	No	No	No	No	No	No	No
111	1	Fault	100	25	100	100	No	No	No	No	No	No	No	No
112	1	Fault	100	50	100	100	No	No	No	No	No	No	No	No
113	1	Fault	100	75	100	100	No	No	No	No	No	No	No	No
114	1	Fault	100	100	0	100	No	No	No	No	No	No	No	No
115	1	Fault	100	100	25	100	No	No	No	No	No	No	No	No
116	1	Fault	100	100	50	100	No	No	No	No	No	No	No	No
117	1	Fault	100	100	75	100	No	No	No	No	No	No	No	No
118	1	Fault	100	100	100	0	No	No	No	No	No	No	No	No
119	1	Fault	100	100	100	25	No	No	No	No	No	No	No	No
120	1	Fault	100	100	100	50	No	No	No	No	No	No	No	No
121	1	Fault	100	100	100	75	No	No	No	No	No	No	No	No

Case 1

TIME	P1	P2	P3	P4	P5	P6	P7
0	2	2	2	2	2	2	2
0.001	2	2	2	2	2	2	2
0.002	2	2	2	2	2	2	2
0.003	2	2	2	2	2	2	2
0.004	2	2	2	2	2	2	2
0.005	2	2	2	2	2	2	2
0.006	2	2	2	2	2	2	2
0.007	2	2	2	2	2	2	2
0.008	2	2	2	2	2	2	2
0.009	2	2	2	2	2	2	2
0.01	2	2	2	2	2	2	2
0.011	2	2	2	2	2	2	2
0.012	2	2	0.215499	0.13101	2	0.13101	0.137173
0.013	2	0.521826	0.818538	0.605013	1.577537	0.608127	0.491036
0.014	1.761657	0.874619	0.001759	0.122087	0.000563	0.902164	0.354231
0.015	0.462211	1.208731	0.302267	0.365431	1.208913	0.487472	0.173279
0.016	0.9581	0.009566	1.460833	0.79915	0.848789	0.755482	0.558639
0.017	1.355884	0.788703	0.172596	0.287209	0.332791	0.598289	0.558454
0.018	1.415346	0.790916	0.566498	0.378291	1.253374	0.119979	0.259258
0.019	1.863103	1.057351	1.577941	0.766663	1.257874	0.32027	0.746536
0.02	1.792823	1.65639	0.939403	1.28266	1.161655	0.848796	1.013053