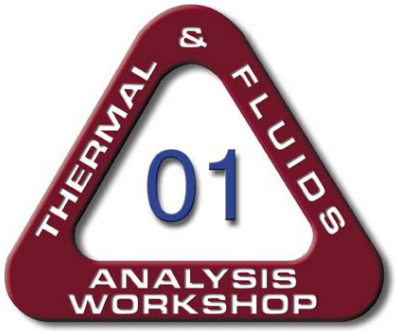

Approximating Fluid Flow from Ambient to Very Low Pressures – Modeling ISS Experiments that Vent to Vacuum.

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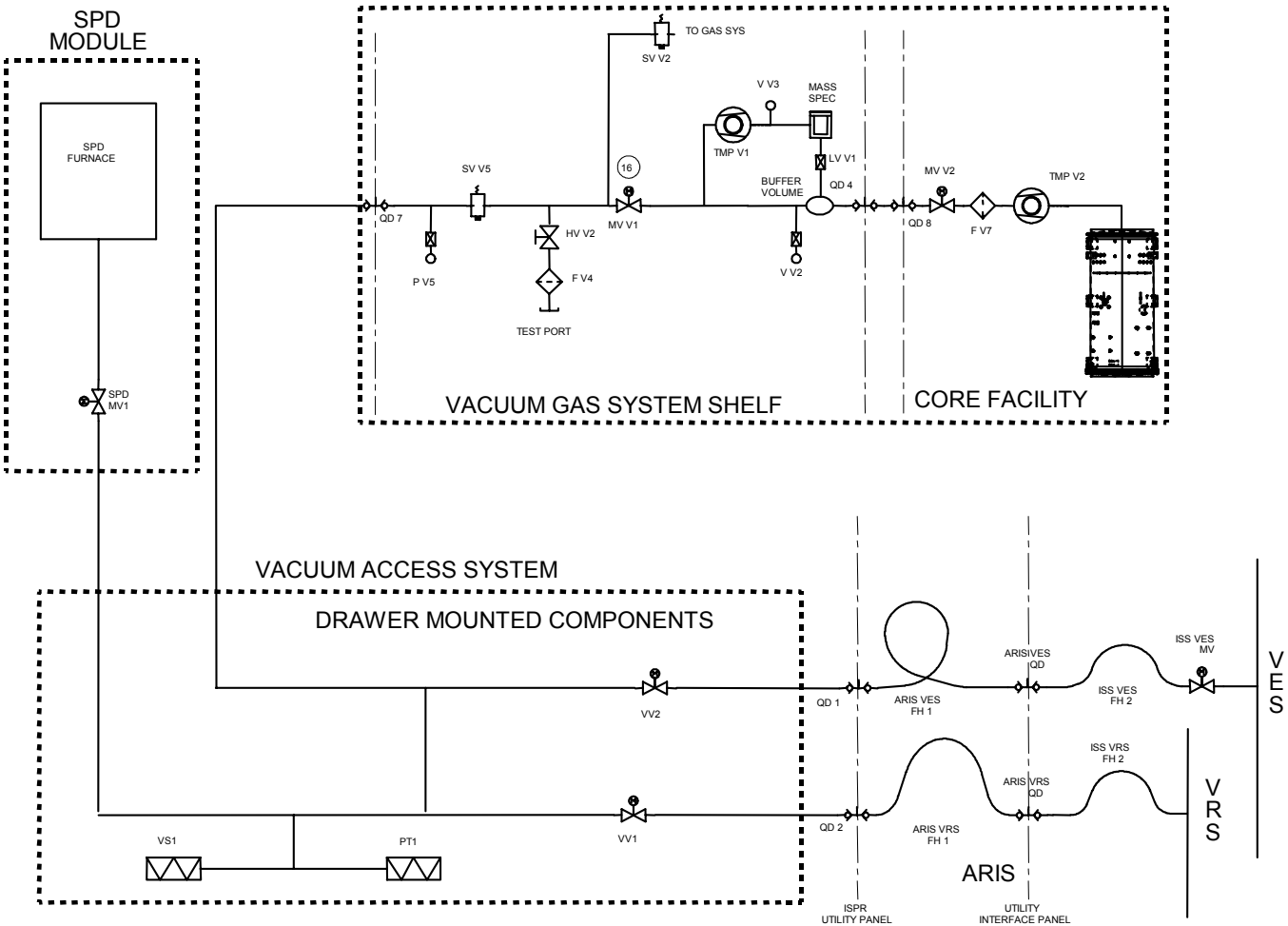
Background

- Two ISS experiment payloads will vent a volume of gas overboard via either the ISS Vacuum Exhaust System or the Vacuum Resource System. A system of ducts, valves and sensors, under design, will connect the experiments to the ISS systems.

Background


SPD
MODULE
SPD
FURNACE
SPD
MV1
TO GAS SYS
SV V2
V V3
MASS
SPEC
TMP V1
LV V1
SV V5
16
BUFFER
VOLUME
QD 4
MV V2
TMP V2
QD 7
HV V2
MV V1
QD 8
F V7
P V5
F V4
V V2
TEST PORT
VACUUM GAS SYSTEM SHELF
CORE FACILITY
VACUUM ACCESS SYSTEM
DRAWER MOUNTED COMPONENTS
VV2
QD 1
ARIS VES
FH 1
ARIS VES
QD
ISS VES
FH 2
ISS VES
MV
V
E
S
ISS VRS
FH 2
ARIS VRS
QD
VV1
QD 2
ARIS VRS
FH 1
V
R
S
VS1
PT1
ARIS
ISPR
UTILITY PANEL
UTILITY
INTERFACE PANEL

The Task

- Create an analysis tool that will verify the rack vacuum system design with respect to design requirements, more specifically approximate pressure at given locations within the vacuum systems.
- Determine the vent duration required to achieve desired pressure within the experiment modules.
- Update the analysis as systems and operations definitions mature.

Unknowns

- Final configuration of rack based vacuum system.
- Some material specific characteristics of the ISS vacuum system, particularly off-gas rates for components with company proprietary material specifications.
- Gas to be vented.
- Gas temperature, pressure and volume.
- Operations scenarios which could impact pressure and temperature of downstream systems.

Known

- Final Configurations of ISS Vacuum Exhaust and Vacuum Resource Systems.
- At some point, in all operations scenarios, there will be a venting of an experiment chamber from ambient to very low pressure.
- Pressure outside ISS is ~1.2e-7 torr.
- Volume outside ISS is infinite.

Three Regimes of Fluid Flow

- Continuum (viscous) flow can be laminar or turbulent, and can be predicted by the laws of conservation of mass and energy.

- Transitional flow has characteristics of both molecular and continuum and is approximated with a conductance method.

Fluid Flow (Continued)

- Molecular flow can be characterized by the mean free path of the molecule (λ). The mean free path is the distance a molecule is predicted to travel with out colliding with another molecule or vessel wall. Molecular flow occurs when λ is relatively large so the likelihood that a molecule will collide with a vessel wall is greater than the likelihood that there will be intermolecular collisions. Molecular flow will be analyzed using a conductance method.

Determining Flow Regime

- Predicting flow regime is accomplished with Knudsen number (Kn).
  - A Knudsen number greater than zero and less than 0.01 indicates a continuum flow regime.
  - The transitional regime will occur where K*n* is greater than or equal to 0.01 and less than or equal to 1.0.
  - A Knudsen number greater than 1.0 identifies the flow regime as molecular flow.
- Knudsen number is calculated by:
  - Kn=0.066/(D*P)
  - Derivation for this equation can be found in the paper.

Determining Pressure

- Two distinct methods of determining the change in pressure over time are employed in order to evaluate performance over all flow regimes
  - Pressure changes through the viscous flow regime are evaluated using the Generalized Fluid System Simulation Program (GFSSP).
  - Flow in the low continuum, transitional, and molecular regimes is predicted using a conductance method.

GFSSP

- Assumes a Newtonian, non-reacting and one-dimensional flow.
- Requires resolution of the system into nodes (internal and boundary) and branches.
- Pressures, temperatures, and concentrations of fluid species are specified at the boundary nodes
- Flow rates are computed in the branches.
- Results are in english units.

Conductance Method

- Flow for the molecular and transitional regimes are predicted by measuring the ability of a gas to flow through a control volume, called conductance.
- In a manner similar to GFSSP analysis a conductance model is developed as a series of connected nodes.
- Control volumes are modeled in terms of pipe and orifice.
- Control volume conductances can be added, in a manner analogous to electrical resistance, so that systems with parallel or series branches can be simplified into single volumes.

Conductance Method (Continued)

$$\dot{P}_j = \frac{1}{V_j}\left[G_j + L_j + C_{ij} * (P_i - P_j) - C_{jk} * (P_j - P_k)\right]$$

Where: $\dot{P}_j$ = Change in pressure in control volume j (torr/sec)

V = Volume (L)

G = Off-gas rate (torr L/sec)

L = Leak (torr L/sec)

C = Conductance (L/sec)

P = Pressure (torr)

i and k are upstream and down stream respectively from j.

Meshing the Models

- GFSSP output becomes the conductance model input file.
  - Design both models so node information mesh.
  - GFSSP calculates in english units, conductance code in SI, be sure to convert.
  - Expect a settling in period, the duration will depend on step size.

Helpful Assumptions for ISS Venting Approximations

- The experiment will either fly at ambient pressure to the station or at some point an on-orbit operation will fill an experiment chamber with station air. This allows for the following assumptions:
  - The gas to be vented is air.
  - Gas temperature and pressure are standard.
- If the valve configuration is under study, let valves open instantaneously.
- Station vacuum systems are vented from ambient pressure along with experiment modules.

Helpful Assumptions for ISS Venting Approximations

- Seals
  - All seals, within the system under design, will leak, the maximum allowable amount, per seal specification.
  - Seals leaking the maximum allowable amount, will not impact continuum pressures, i.e. GFSSP model.
  - Seals within Vacuum Exhaust and Vacuum Resource systems do not leak.
  - Other experiments connected to these vacuum systems do not leak.

Helpful Assumptions for ISS Venting Approximations

- Off-gassing is described by an exponential decay function.
  - Pressure must be low enough for the escape of entrained gases to be significant, which won't occur to a noticeable degree in continuum regime.
  - When off-gassing rates are unavailable use a known rate for a material with chemical similarities.

Conclusions

When designing a new analysis tool:

- Gather information from system designers, operations planners, and principal investigators,
- Fill in the blanks with assumption,
- Create modular software,
- Share results,
- Iterate.