ABSTRACT

The ALADIN laser instrument is developed by ASTRUM SAS for the European Space Agency. A passive mechanism named Pressure Relief Valve (PRV) has been developed in the frame of this program.

The paper presents the major features of the mechanism design and development.

1 CONTEXT

1.1 The ALADIN instrument – AEOLUS mission

The Atmospheric Laser Doppler Instrument (ALADIN) is the payload of the ADM-AEOLUS mission (figure 1), which will make direct measurements of global wind fields. It will determine the wind velocity component normal to the satellite velocity vector. ALADIN (figure 2) is a Doppler Lidar operating in the near ultra-violet spectral region using backscattered signals from aerosol at low altitude and from air molecules at high altitudes. It will be the first of its kind in space.

ALADIN is now in its final construction stage: the integration of the Flight Model is on-going. Most of the subsystems have been integrated; the payload performance and qualification test campaign will commence.

In order to prevent LIC effects, the sealed cavities in which the sensitive optics are located have to be pressurized with oxygen at low pressure (few tens of Pa). During launch ascent phase, the external pressure will decrease from 1 bar down to 0 bar. But the cavities can not withstand a pressure difference of more than typically 100 mbar.

Consequently, to avoid damage due to overpressurisation of the sealed cavities during launch ascent phase, a dedicated (passive) pressure relief valve (PRV) needs to be accommodated. As this need has been identified late in the program development, there was no remaining actuation electrical line from the AEOLUS platform to allow for the selection of an active device. As a consequence, the valve had to be passive.

The companies RTG and LEE Viscojet were consulted. Due to the very low pressure range required, together with stringent sealing and contamination requirements not any suitable device has been identified from the market.

So, a custom Pressure Relief Valve (PRV) has been designed and developed by Astrium France, during the year 2010. It exhibited a pressure difference that did not exceed 60 mbar, even during launch vibrations.
## 2 DESIGNING THE PRESSURE RELIEF VALVE

### 2.1 Specification requirements

The specification requirements are detailed herebelow.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive device</td>
<td>To be only operated by the pressure difference $\Delta P$ between inner and outer environment</td>
</tr>
<tr>
<td>Closure threshold</td>
<td>The valve shall close and remain closed permanently when $\Delta P$ is lower than 4 mbar</td>
</tr>
<tr>
<td>Maximum pressure difference $\Delta P$</td>
<td>Relief valve aperture shall be such that the $\Delta P$ shall remain as close as possible to 40 mbar with a maximum target that shall never exceed 60 mbar, even under vibrations.</td>
</tr>
<tr>
<td>Cavity volume</td>
<td>The valve shall be adjustable to cope with units inner volumes in the range [10-18] litres.</td>
</tr>
<tr>
<td>Mass</td>
<td>$&lt; 0.2$ kg</td>
</tr>
<tr>
<td>Leak rate</td>
<td>In closed position, the leak rate (flow rate) through the valve shutter shall be lower than 0.001mg/s of oxygen when $\Delta P = 0.8$ mbar. In particular, this performance shall be fulfilled after mechanical and thermal environment qualification testing.</td>
</tr>
<tr>
<td>Cleanliness</td>
<td>A special care shall be brought to the cleanliness of components in the vicinity of the aperture, where contamination could be brought inside the units inner cavities</td>
</tr>
</tbody>
</table>

### Pressure decay law (under fairing)

![Pressure decay curve](image)

*Figure 5-13: Variation of Fairing Static Pressure during Ascent.*
2.2 Design overview

A passive valve based on two parallel preloaded blades was designed. Blades design and preload were optimised to ensure opening when the pressure difference $\Delta P$ exceeds 40 mbar. Hole size is diameter 17.6 mm at aperture level.
### Materials

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blades</td>
<td>Titanium</td>
</tr>
<tr>
<td>Structural parts</td>
<td>Titanium</td>
</tr>
<tr>
<td>Gaskets</td>
<td>Silicone</td>
</tr>
</tbody>
</table>

| Mass            | 0.063 kg (including a mobile part of 0.0136 kg) |
| Size            | 77 mm x 22 mm x 32 mm |

| Bladed preload  | 0.90 N          |
| Aperture threshold | ΔP = 40 mbar    |
| Bladed bending stiffness | 950 N/mm ± 6 % |

The two parallel blades ensure a pure translational motion, in order to avoid any uncontrolled rotation of the shutter, that could degrade the sealing performance.

2.3 Development

The following models were developed: 2 QM + 3 FM. The use of 2 Qualification Models (QM) offers some visibility on potential dispersion during tests.

The valve behaviour was to be verified during vibrations, requiring a specific test jig. Vibrations and thermal tests were only performed on QM1 and QM2. On Flight Models (FM), only functional tests were performed.

3 SIMULATIONS AND ANALYSES

The flow rate can be subsonic or sonic, depending on pressure ratio:

- If \( \frac{p_e}{p_o} > \left( \frac{2}{\gamma+1} \right)^{\gamma-1} \), the gas flow is subsonic, depending on forwards and backwards conditions.

\[
\frac{dm}{dt} = C_d A \left( \frac{2}{\gamma-1} \right)^{\gamma-1} \left( \frac{p_e}{p_o} \right)^{\gamma-1} - \left( \frac{p_e}{p_o} \right)^{\gamma+1}
\]

With:

- \( p_o \) Internal pressure inside the cavity
- \( p_e \) External pressure
- \( C_d \) Discharge coefficient
- \( A \) Valve passing area
- \( \rho_o \) Specific mass of backwards gas
- \( \gamma \) Adiabatic coefficient of the gas (air: \( \gamma = 1.40 \))

- If \( \frac{p_e}{p_o} < \left( \frac{2}{\gamma+1} \right)^{\gamma-1} \), the gas flow is sonic, only depending on backwards conditions

\[
\frac{dm}{dt} = C_d A \left( \frac{2}{\gamma+1} \right)^{\gamma-1} \left( \frac{2}{\gamma+1} \right)^{\gamma-1} \left( \frac{p_e}{p_o} \right)^{\gamma+1}
\]

In case of air flow, \( \left[ \gamma / (\gamma+1) \right]^{\gamma / (\gamma-1)} = 0.528 \). Thus:
- at the beginning, \( p_e / p_o = 1 \) and air flow is subsonic
- at the end of launch phase, \( p_e / p_o = 0 \) / (40 mbar) = 0, and air flow becomes sonic.

![Figure 5 - The Pressure Relief Valve](image)

![Figure 6 - Cavity pressure decay prediction](image)
Max ΔP: 47.7 mbar
Max force on shutter: 1.16 N
Max aperture: 0.277 mm
Max decay rate: 49.6 mbar/s

The maximum ΔP predicted value was higher than the specified 40 mbar, but fluidic tests exhibited that it was preferable to improve sealing performance, by selecting a higher preload.

4 TESTS

Some details are given for the key performances of the PRV.

4.1 Pressure Relief Valve behaviour

The PRV behaviour has been characterized by recording the load applied on the shutter as a function of the shutter displacement.

Test results

The valve behaviour can be divided in 3 parts.

Part 1: The load applied on the shutter is lower than the preload. Therefore the shutter of the valve remains closed: the slope of the green curve is equal to the stiffness of the silicone gasket.

Part 2: The load applied on the shutter reaches the preload value. However the evolution of the load is not linear. The valve behaviour exhibits some gasket sticking. The passive relief valve is not completely opened.

Part 3: The load as a function of the shutter displacement is linear, and the slope of the curve corresponds to the bending stiffness of the paired blade: the passive relief valve is opened.

Conclusion: The PRV behaviour and its main characteristics, (i.e. the preload and the bending stiffness), are consistent with the prediction. Moreover some gasket sticking appears during the shutter opening.

4.2 Model validation

The objective of this test is to validate the model used to predict the pressure drop evolution across PRV during the launch ascent phase (see §3).

The depressurization downstream the PRV has been generated by a vacuum pump and regulated by using an adjustable valve. On each PRV, several depressurization profiles have been tested.

Test results

All the tests performed do confirm the prediction of the overpressure evolution upstream from the PRV during the launch ascent phase. It is noticeable that, owing to some gas leakage through the PRV, the measured overpressure is slightly lower than predicted (all maximal overpressures measured are nearly 2mbar lower than predicted ones).

Conclusion: The model has been validated and has confirmed that the maximal overpressure upstream each PRV during the launch ascent phase will be lower than 47 mbar. However gasket sticking and launch vibrations may increase the maximal overpressure.

4.3 Impact of the gasket sticking

In order to measure the impact of the gasket sticking during the launch ascent phase, the load applied on the shutter before the PRV opening, has been measured as a function of the shutter displacement. The depressurization profile (i.e. the load increase on the shutter) has been simulated using a mechanical testing machine.
This test has been performed for several closure durations, with a loading profile versus time representative of the launch phase.

**Test results**

![Figure 9: Impact of the gasket sticking](image)

In a first time, the gasket sticking impact increases with the shutter closing length and then seems to tend to an asymptotic value.

**Conclusion** When the valve remains closed during less than 7 days, the impact of the gasket sticking on the maximal overpressure upstream the PRV during the launch ascent phase is lower than 6 mbar.

4.4 Impact of the launch vibrations

During the launch ascent, the vibrations may generate an increase of the overpressure upstream from the PRV owing to potential uncontrolled closures of the shutter. Therefore the impact of vibrations on the overpressure has been evaluated by measuring the overpressure variations during the vibration acceptance level with the valve maximum aperture predicted (the valve maximal aperture was generated with a nitrogen flowrate).

**Test results**

![Figure 10: Impact of the vibrations](image)

The maximal impact of the vibrations on the overpressure upstream each PRV is contained between 2.5 and 6.5 mbar. It is important to notice that these values are conservative since the gas density upstream the PRV remains identical to ambient pressure while during launch the air density will decrease. Therefore identical displacements of the shutter of the PRV generated by the vibrations during the on-ground testing and during the launch phase will generate a higher overpressure during the on-ground test.

**Conclusion** The impact of the vibrations on the maximal overpressure upstream the PRV during the launch ascent phase is lower than 6.5 mbar. Therefore, taking into account the gasket sticking and the vibrations, the overpressure will not exceed 60 mbar.

4.5 Leak rate

The leak tests have shown that the oxygen flow rate, for an overpressure of 0.8 mbar, remains lower than the specification (0.001 mg/s).

4.6 Vibrations and thermal tests

The vibrations and thermal tests sequences have been successfully performed: no damage and no performance evolution have been detected after vibrations and thermal tests.

5 CONCLUSION

Comparing the measured performances with respect to model predictions was of paramount interest. Moreover the combination of fluidics and mechanical issue leads to implement complex test methods and contributed to increase the teams’ expertise. The leak rate of the PRV was finally much lower than expected. This allowed us to decrease the oxygen consumption allocated to the PRV, in order to increase the allocation of the other equipments.