Concepts for Follow On Missions

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## Follow On Missions: Background

Wind profiles are emerging as a requirement for post European Polar System.

How could this requirement be satisfied, at minimum cost, in period up to 2019?
- Implies minimal design changes to Aeolus design
- Implies improved lifetime

More ambitions requirement could be satisfied but at a more ambitions budget.

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<td>Aeolus Lifetime</td>
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<td>First post EPS Launch</td>
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<td>Wind Profile Data Gap</td>
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Follow On Mission: Issues Studied

- Agency and Astrium have worked on concepts for lowest cost follow on missions.

- Astrium (Aeolus prime) have conducted study at their own cost. Result is a TN “Aeolus Follow-On Study” (AE-TN-ASU-SY-00131, Iss 1):
  - TN is freely available to interested parties

- Astrium TN covers following potential mission improvements:
  - More height bins
  - Second line of Sight
  - Lifetime extension
  - ALADIN instrument on MetOp
  - Coverage improvements

- Astrium have also studied programmatic to avoid data gap.

- Astrium have not provided cost figures. These have been worked up by ESA Aeolus project
Follow On Mission: More height bins

Following binning improvements appear compatible with short development times and relative minor cost increases:

<table>
<thead>
<tr>
<th>Max Attitude</th>
<th>Aeolus</th>
<th>Follow on</th>
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<tbody>
<tr>
<td>Max No of Height Bins</td>
<td>24</td>
<td>~ 50</td>
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<tr>
<td>Minimum Height Bin</td>
<td>250 m</td>
<td>150 m</td>
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<tr>
<td>Max Height Bin</td>
<td>8 Km</td>
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</table>

Measurement Accuracy predicted with existing transmitter and receiver design. Doubling bin height improves accuracy by $\sqrt{2}$ for homogeneous atmosphere.
Follow On Mission: Design for more bins

- Primary Requirement for more bins is bigger CCD. Can re-use Aeolus cell layout

- Height bins less than 150 m would:
  - Require major electronic redesign
  - Decrease measurement accuracy by $\sqrt{H_A/H_B}$

- Data rate change could be accommodated without major design changes:
  - Non-transmission of unfilled data packets
  - Use of lossless compression techniques
Follow On Mission: Second Line of Sight

- Accommodation of several lines of sight on one spacecraft would require a totally new design concept.

- A Modification of the Aeolus concept to sense “backwards” along the track is possible using most of the same building blocks as the existing design.
  - Instrument receiver would need to operate at different multiple of Free Spectral Range
  - Instrument baffle to be re-designed
  - Some changes to thermal design of spacecraft
  - Pointing requirements not significantly more stringent than for Aeolus.

- Two spacecraft simultaneously in orbit would give 2D wind information, and would also provide some in-orbit redundancy.

(a) Nominal Aeolus observation scenario (b) Orthogonal observation scenario
Follow On Mission: Lifetime

Propellant

Modest increase in orbit height produces a dramatic improvement in propellant lifetime for a very small performance decrease.

Laser Pump Diodes

On-going lifetime testing of Aeolus pump diodes consistent with 39 month lifetime. Technology improvements at LD manufacturers show indications of very much longer lifetimes. More evidence will be available before launch of Aeolus.

Laser Induced Damage on emission path

Qualification for Aeolus has selected components and coatings with adequate LID margins at EOL. Extension of mission by e.g. factor 2 is within these margins for most components. A few would need to be changed.

Contamination

Careful materials selection, bake-out and purging all used for Aeolus. Molecular absorbers incorporated in design. Any residual contamination is expected to lead to a gradual degradation. Flight standard laser will be tested for six months in vacuum prior to launch. Use of molecular absorbers could be extended in future missions at relatively minor cost.
Follow On Mission: Lifetime Conclusion

- Instrument Lifetime limitations are Laser Induced Damage, Laser Pump Diodes and Contamination.
  - Laser Induced Damage thresholds for components and coatings seem compatible with a doubled lifetime.
  - Laser Pump Diodes will be available for a follow on mission with much improved lifetime.
  - Residual contamination risk will be quantified before Aeolus launch and could be further reduced with only minor modification using additional molecular absorbers.

- Instrument degradation is expected to be either sudden at Beginning of Life or gradual over lifetime.
  - Six month on ground Laser vacuum test before launch

- Fuel for doubled lifetime available at cost of modest performance decrease.

- Safe to assume that minor modifications to Aeolus design can ensure five year follow-on lifetime.
  - To be confirmed after six months of Aeolus in-orbit experience
Follow On Mission: Aladin on MetOp

- MetOp and post EPS platforms will fly at ca 800 Km.
- Aeolus flies at 400 Km. To fly at 800 Km altitude would require:
  - 480 mJ output per pulse in UV (cf. 120 mJ for Aeolus)
  - 3 m diameter telescope (cf. 1.5 m for Aeolus)
  - some combination of the above
- Higher altitude instrument significantly more demanding than ALADIN with respect to mass (500 Kg for ALADIN), power (850 w ALADIN) and cost (ca. 100 M€).
- ALADIN already uses 55% of the mass and 90% of the peak power of the current MetOp payload capacity.

Conclusion:
- Not feasible to add wind lidar to MetOp payload
- Not feasible to fly wind lidar on 800 Km on post EPS platform
Follow On Mission: Coverage

- Polar Orbit at 400 Km gives global coverage each day:
  - Along Track pixel size is ca 50 Km
  - Along Track pixel separation ca 200 Km

- Several spacecraft simultaneously in orbit can be phased to reduce inter track spacing
  - Also provides in-orbit redundancy

- Each spacecraft produces data roughly equivalent to all existing radio-sonde data.

- PIEW Study (Stoffelen et al) shows little improvement in forecasting of extreme events with more than two spacecraft.

- ECMWF will measure impact of Aeolus on NWP.
Follow On Mission: Orbit Changes

• Changes of orbit inclination could improve coverage at lower latitudes.

• Changes in Local Time of Ascending Node (LTAN) could provide coverage at different local times.

• Either such change would imply major thermal and power re-engineering of the satellite.
  - Orbit no longer dawn/dusk so much greater variations in sunlit/eclipse periods.
  - Solar Array Size would need to be significantly increased as would battery.
  - Solar Array would need to be rotating not fixed.

• Conclusion: Orbit changes not compatible with minimum cost programme.
Follow On Mission: Programatics to Avoid Data Gap

- Financial Commitment for Long Lead Items required in Mid 2008.
  - Could be dependent on successful outcome of six months vacuum test on Flight Space Laser
  - Will be after Airborne Campaign with Aeolus Airborne Demonstrator

- Financial Commitment for Satellite(s?) required in Mid 2009.
  - Could be dependent on successful outcome of first six months in-orbit

- First Satellite would be in-orbit in 2012. Would avoid data gap.

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<th>Start Date</th>
<th>Start Month</th>
<th>Start Year</th>
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Follow On Aeolus: Mission Model

- Assume four Satellite programme with LLI procurement before Aeolus launch and all four Satellites ordered after six months operational experience:
  - Later ordering will increase costs significantly due to industrial run down/start up.
  - Staggered ordering would also substantially increase costs.
  - Include some provision for re-engineering for obsolete parts, binning changes and minor lifetime improvements but no other engineering changes.

- Assume satellite lifetime is 5 years.
  - Allows 2 satellites in-orbit after mid 2013 in accordance with PIEW recommendation and to provide in-orbit redundancy.

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<td>Average no. of satellites in operation</td>
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- Assume re-use of Aeolus operational infrastructure
  - Command and Control costs minimal. One pass per day, Weekdays only unless availability improvement required.
  - X-band downlink to one station only with 2.4 m antenna.
  - Improved delivery times would required more stations.

- Assume ESA/EUMETSAT procurement strategy as per MetOp and MSG.

- Assume Launcher procurement as free market but acknowledge current price trends.
### Follow On Aeolus: Mission Model

<table>
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<th>Cost Item at 2006 e.c.</th>
<th>Low Estimate</th>
<th>High Estimate</th>
<th>Comment</th>
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<td>Industrial Cost</td>
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<td>430</td>
<td>No start up costs. 20 M€ LLI in 2008. All Satellites ordered together</td>
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<td>ESA Internal Cost</td>
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<td>60</td>
<td>Scaled on existing team size</td>
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<tr>
<td>Launch Costs</td>
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<td>90</td>
<td>Reflect market trends</td>
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<tr>
<td>Operations Costs</td>
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<td>120</td>
<td>Re-use ESA Infrastructure</td>
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<td>EUMETSAT Costs</td>
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<td>Not Included</td>
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<td><strong>TOTAL</strong></td>
<td><strong>580</strong></td>
<td><strong>700</strong></td>
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**ESA Project Team Estimates on Stated Assumptions:**
- Costs based on historical costs of Aeolus and procurement experience of MSG and MetOp.
- Costs achieved depend heavily on conditions at time especially competitive position of prime.
Follow On Aeolus: Conclusions

- A follow on programme is feasible which would avoid a data gap until post EPS is available.

- Some minor engineering changes could be included, particularly an increased number of height bins and improved lifetime.

- A programme with two satellites in-orbit after mid 2013 would reflect conclusions of PIEW study and provide in-orbit redundancy.

- Lowest possible cost requires some risk taking:
  - 20 M€ LLI’s ordered in 2008
  - All Satellites ordered together after 6 months of in-orbit experience with Aeolus.

- Cost of 4 Satellite programme would be between 580 and 700 M€ (2006 e.c.) excluding EUMETSAT costs.

- Cheaper programmes possible with only one satellite in-orbit.

- Lower risk programmes possible at higher cost, but would not assure data continuity.