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Mounts for large lens in cooled environment

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Abstract—For the future space missions as Cosmic Vision, the working temperature of the optics can be very low even for visible applications. This is due to the L2 environment. Thus, in the PLATO mission, a dioptric imaging solution based on lenses with diameters up to 180 mm and temperature around 190 K was selected. Furthermore, for EUCLID mission, the dichroic blade associated to a diameter of 120 mm and a temperature of 150 K is one of the key elements. Such large optical components working in a cooled environment are not easy to implement. Classical mounting solutions qualified for small optics are no more relevant for next generation of scientific applications. Thales Alenia Space has proposed, designed and developed, in the framework of a CNES R&T activity, a mechanical concept for the mounting of large refracting components (180 mm diameter) compatible with mechanical loads (30 g) and thermal environment (150 K) . A full size breadboard has been realized and tested.

Keywords—lens; mounting; cold temperature; optics; space

I. INTRODUCTION AND OBJECTIVES

A. Context

Up to now, for space instruments, refracting components are used either at room temperature for large lenses in visible applications (stars tracker, COROT, S3 ...) or at cooled temperature for small components in IR applications (IASI, MSG, MTG ...). For next generation space telescopes, large lenses or large optical blade are intended to be used at cooled temperature. In particular, for the future Cosmic Vision missions, due to the L2 environment, the working temperature of the optics can be very low even for visible applications. It is the case for the PLATO mission: a dioptric imaging system based on lenses with diameters up to 180 mm and temperature close to 190 K was selected. For EUCLID as well, the dichroic blade with a 120 mm diameter is designed to be at a temperature of 150 K. This component is one of the key elements of the mission.

Such large optical components used in a cooled environment are not easy to implement. Classical mounting solutions qualified for small optics are no more relevant for next generation scientific telescopes. The challenge is to keep the glasses aligned without any surface deformation in a minimum of volume allowing doublet or triplet devices which are often used for camera designs.

B. Mounting requirements

Some key specifications have been derived from PLATO (Fig 1) and EUCLID requirements. The acceptable deformation is one of these challenging specifications.

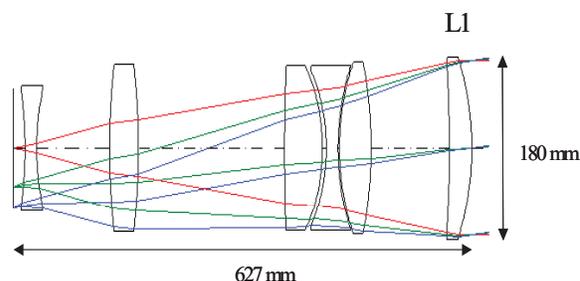


Figure 1. Optical Thales Alenia Space design for PLATO mission

The acceptable misalignments during operational life (at cold temperature) have been assessed in order to fulfill the end of life requirements. The mounting solution shall prevent from misalignments higher than :

- +/- 5 μ m for decentering
- +/- 50 μ rad for tilt

The acceptable lens deformation (due to the mounting mechanical stresses on optics) is driven by the EUCLID mission where the dichroic blade reflects the visible light. The maximum allowed deformation, in this case, is expressed as a maximal wave front error (WFE) :

- WFE < 10 nm RMS

An other important requirement for the mounting design is to be able to realize doublet or even triplet with the solution (as presented in the Fig 1):

- Mechanical mount shall be compatible with doublet or triplet solutions.

These requirements have been used to verify the compliance and the relevance of the proposed solution.

II. SELECTED CONCEPT

A. Trade-off criteria

Different solutions have been identified and analyzed for the mounting. A trade-off between 12 candidates has been performed based on the criteria summarized in the following table :

TABLE I. LIST OF CRITERIA USED TO SELECT THE SOLUTION

N°	Listed by order of decreasing importance	
	Criteria	Comments
1	Large lens compatibility	Relevance to large optics
2	Doublet compatibility	Possibility to accommodate doublet
3	Mechanical loads	Possibility to withstand launch loads
4	Thermo-elastic efficiency	Minimization of stresses in cooled environment
5	Mass	Minimization of the needed mass
6	Triplet compatibility	Possibility to accommodate triplet
7	Thermal conductance	Maximization of thermal uniformity
8	Cleanliness	Compatibility with cleanliness procedure
9	Alignment	Alignment shall be eased as much as possible

The best solution has been selected after a rigorous analysis of each above criteria.

B. Concept description

The proposed concept (Fig 2) is based on a light weighted mechanical ring glued on the 180 mm diameter of glass thanks to a number of 12 pantographs which give the needed mechanical flexibility for the cooled environment. The barrel is made in titanium in order to match the CTE of the glass.

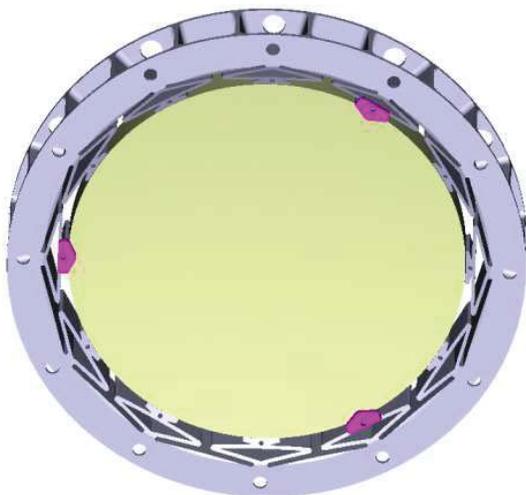


Figure 2. Mechanical concept proposed for large lens in cooled environment

This design is very compact in axial direction and have a sufficient flexibility in radial direction to compensate the CTE difference between the glass and the mount.

C. Design justification

A finite element model (FEM) has been developed and used for the concept validation. The mechanical behavior has been derived from this FEM for the mounts under mechanical loads (representative of launch) and thermal environment (down to 150 K). It has been verified that the proposed solution fully complies with the requirements given in the chapter I. The first Eigenfrequency (Fig 3) in radial direction is given by the pantographs mode and is above 400 Hz . In axial direction, the value is higher than 430 Hz.

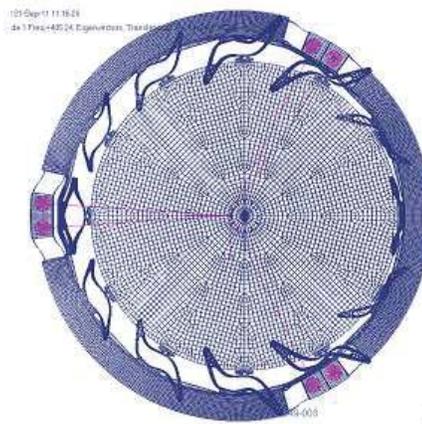


Figure 3. FEM analysis : first Eigenfrequency in radial direction higher than 400 Hz

D. Full camera description

An important advantage of the proposed concept is its capability to accommodate a full camera design even in presence of doublets or triplets thanks to its compactness (Fig 4).

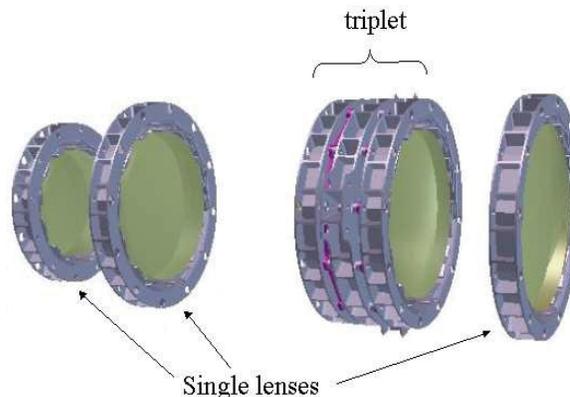


Figure 4. Solution applied to the PLATO camera

The PLATO camera has been used to apply the solution and to verify that triplet are feasible and that the global performance of the mission can be met in cooled environment.

III. BREADBOARD DESIGN

Based on the performed study, Thales Alenia Space has developed a breadboard to demonstrate the modeling predictions and to qualify the solution.

A. Breadboard description

The mockup is fully representative of the solution dedicated to space application (Fig 5). The ring is made of Titanium and has been manufactured in one single piece of metal. The supplier was able to respect the final specified geometry with an accuracy of 20 μm .

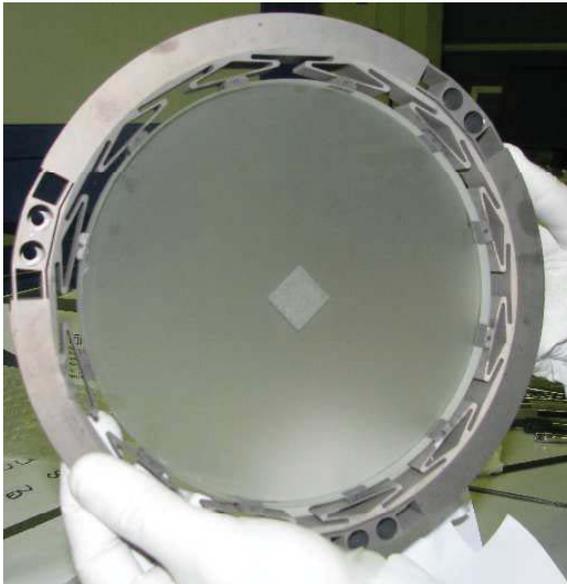


Figure 5. Scale 1 breadboard design for space applications. A centered mark is accommodated to ease the WFE exploitation.

The glass is made in BK7 with a grounded rear face in order to avoid ghost reflection during optical test. Its useful diameter is 180 mm in order to be representative of PLATO and EUCLID needs.

A very precise finite element model has been developed in order to verify that there is no risk of damage during tests and also to get accurate predictions of lens deformation in cooled environment. The surfaces dedicated to the glued areas have been carefully simulated (Fig 6).

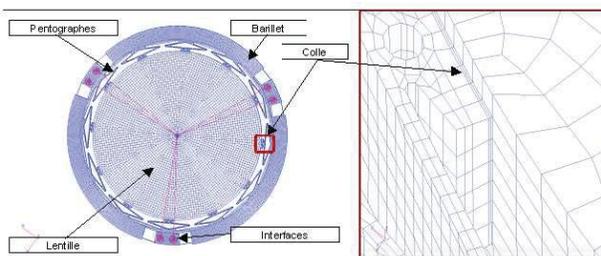


Figure 6. Breadboard precise FEM used for test predictions

B. Performance assessment

The cooled down effect has been calculated using the FEM for both applications :

- 190 K to cover PLATO needs
- 150 K to cover EUCLID needs

The surface deformation (difference between ambient conditions and cold environment) occurs mostly at the pantograph interfaces (Fig 7). It is limited to few tens of nanometers peak to valley (PV). The global performance of WFE better than 10 nm can be achieved theoretically.

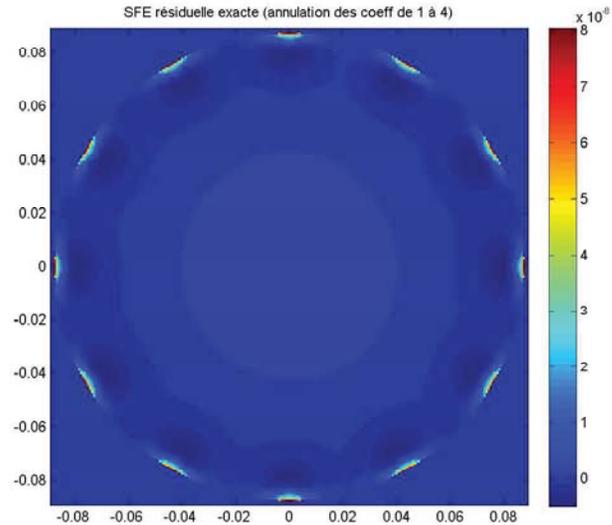


Figure 7. Prediction of the deformation between ambient and 150 K for the surface front error (SFE). The predicted WFE for the reflected beam equal to $2 \times \text{SFE}$ is lower than 10 nm RMS.

It has to be pointed out that if we take into account the whole clear aperture of the optic, the global deformation is compliant with the EUCLID requirement. It could be possible to improve even more this result by reducing the collecting area (by implementing a diaphragm). If the optical useful area is reduced (or if optics are slightly oversized), the WFE decreases to only few nm (no more edge effects).

C. Test plan

The following sequence has been applied to the breadboard in order to validate the predictions and thus validate our design for large refracting components used in cooled environment.

- WFE measurement at ambient (reference)
- WFE measurement at 190 K (verification of PLATO compliance)
- WFE measurement at 150 K (verification of EUCLID compliance)

Then a space qualification has been applied to the breadboard through a full thermal cycling and vibration tests.

IV. TEST SET UP

A. Test configuration

The mockup has been installed inside a cold chamber under vacuum and controlled thermal environment (Fig 8).

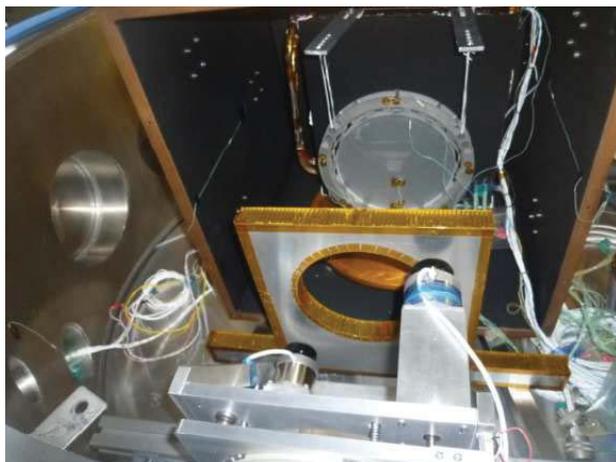


Figure 8. Breadboard in its vacuum chamber for optical tests

Special care have been taken to guaranty a good thermal homogeneity during the measurements. In this way, the thermal conductive leakage through the support has been minimized by design. The control of the breadboard temperature is mainly assumed by radiative exchanges.

The interferometer is placed outside the vacuum chamber but its reference blade is kept inside in order to minimize the window perturbations of the chamber and to avoid turbulence effect.

B. Test sequence

When the thermal level is reached, the optical measurements are performed with a Zygo interferometer on a sub-pupil around 10 cm of diameter. Three different positions are carefully scanned (Fig 9). Each position has been chosen in order to get the characterization of the edge deformation.

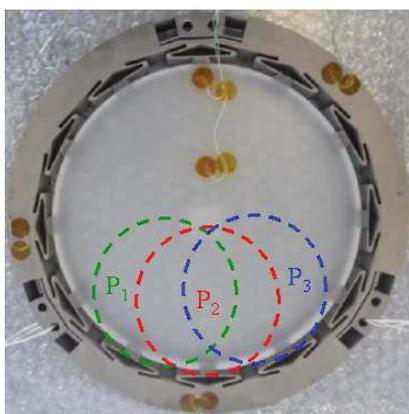


Figure 9. Measurement at 3 sub pupils level (P1, P2 and P3) in order to point out the edge deformation

V. TEST RESULTS

A. Measurements philosophy

As the predicted deformations are very small except at the edge, we have decided to include the edge in the measured areas (Fig 10).

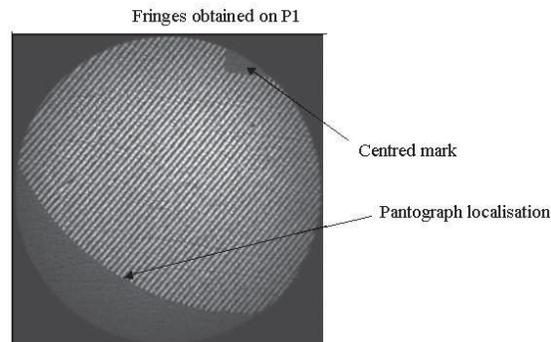


Figure 10. Example of fringes obtained on P1 position in vacuum and in cold temperature

Two kinds of exploitation can be done :

- In the unvignetted area for global WFE measurements
- At edge vicinity for local deformation measurement

B. Global deformation at cooled temperature

For the measurement exploitation, we have proceeded to the differences between the measured WFE at cold temperature (190 K or 150 K) and the reference measurement (at ambient). The point to point difference between both WFE maps was eased thanks to the centered mark on the glass. Each difference reveals high frequency defects (scratches) which are due to the chamber window (Fig 11). These blemishes can be easily removed by a low frequencies filtering using Zernike polynomials. In the following figure, the dash circle gives the limit of the area used for this analysis. This filtering is valid and does not affect the glass deformation estimation since the mount effect only generates low frequencies deformation.

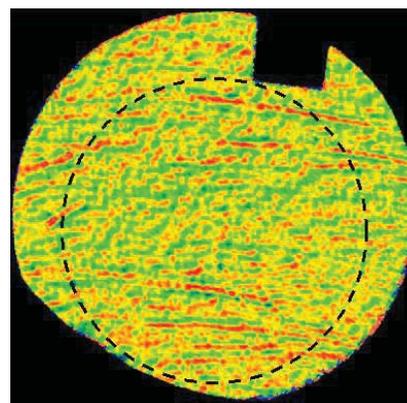


Figure 11. WFE difference between the reference (WFE measured at ambient) and the WFE at cold temperature (150 K here).

Once high frequencies removed, the residual deformation from ambient to low temperature is given in the following figure (Fig 12).

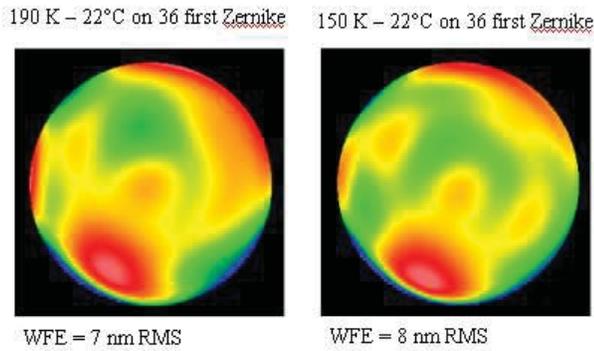


Figure 12. Measured deformation in cooled environment on sub pupil P1. On the left, deformation from ambient to 190 K. On the right, deformation from ambient to 150 K

Remark : in these measurements all the perturbations generated by the test setup itself are also included (thermal gradients , temperature changes of the interferometer reference blade ...). The real part link to the glass deformation is thus smaller than what has been measured.

We found similar values on each sub-pupils. It confirms that global deformation of the glass at low temperature is lower than 10 nm as predicted.

C. Local deformation at cooled temperature

Since measurements contain the edge of the glass, it is possible to analyze the pantograph interface areas. To do that, working with the high frequencies map is mandatory even if defects from the window are present. The raw WFEs have been used and cuts in both directions analyzed (Fig 13).

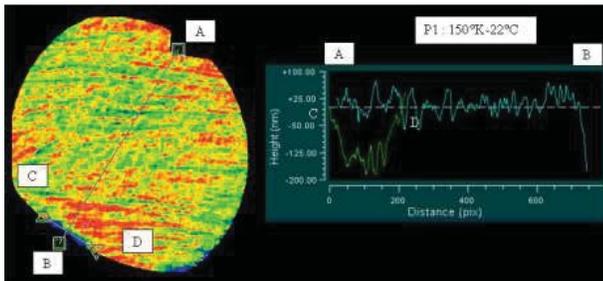


Figure 13. Raw WFE measured at 150 K. Edge effect are visible. The cuts are given for both directions [AB] and [CD]. Measured deformation in local pantograph area is 180 nm PTV

The measured amplitude of the local deformation is around 180 nm PTV which is very close to the calculated value of 160 nm PTV. Moreover, the dimension of the affected area by the pantograph interface is very similar to the predicted one (Fig 14).

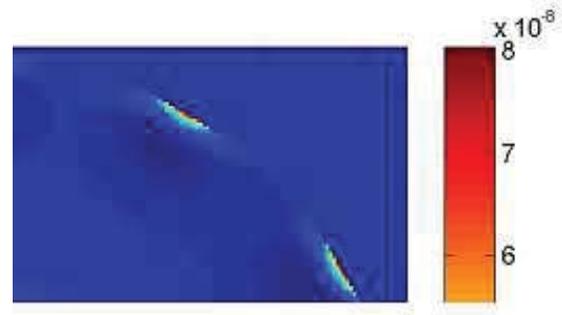


Figure 14. Predicted deformation at 150 K due to the pantograph interface. Mechanical surface deformation is calculated around 80 nm PTV which is equivalent to WFE for reflected light of 160 nm.

Here again, the predicted values from breadboard FEM are very close to the measured one.

D. Hysteresis verification

The reference measurement has been done at the beginning of the test sequence (at ambient temperature under vacuum) but a second reference has been done just after the sequence when the setup is back to ambient temperature (still under vacuum). The difference between these both references shows how accurate the measurement is (Fig 15).

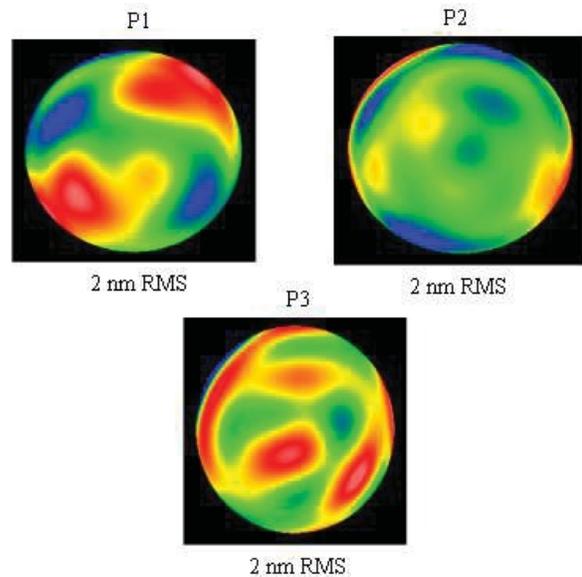


Figure 15. Differences between both reference measurements (at ambient) before the test sequence and after. Analysis performed for all scanned sub pupils (P1, P2 and P3).

This analysis allows to conclude that no damage with optical incidence appears during the breadboard cool down and no hysteresis has been identified. The global accuracy of the performed measurement is around 2 nm.

VI. SPACE QUALIFICATION STATUS

Once the compliance of the proposed solution with future space missions demonstrated, the space qualification of this solution has been verified.

A. Thermal cycling

The breadboard has been submitted to thermal cycling as usual applied for space qualifications. Each cycle goes from 300 K down to 150 K with a slope of 12 K/h (Fig 16). A number of 8 cycles has been selected and is fully representative of the thermal environment of a space component in a payload like PLATO or EUCLID.

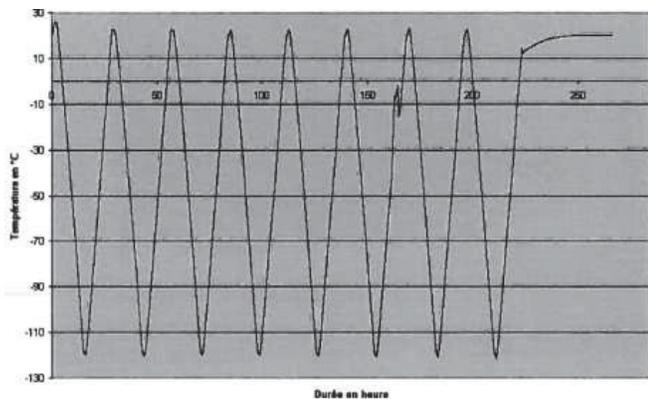


Figure 16. Thermal cycling successfully applied to the breadboard. Duration is in hours

No evidence of damage has been identified after this cycling test.

B. Mechanical test

At time being, the breadboard is prepared to face a vibrations test performed by CNES. The design is able to withstand quasistatic loads around 30 g without any performance degradation. This is compatible with the typical levels encountered by optics in space payload. It is important to verify that the proposed solution was not only designed to comply with thermo-elastic requirements which need some mechanical flexibilities but also with launch requirements which need some stiffness.

VII. CONCLUSION

During this R&T activity, a mechanical design has been proposed with the view to not disturb the optical quality of large refracting elements used in cooled environment. It has been demonstrated, through accurate modeling, that the solution complies with stringent requirements as PLATO or EUCLID needs.

A breadboard has been successfully developed and tested in representative conditions. The finite element modeling (FEM) was fully validated based on the very good correlation between measurements and predictions. The absence of hysteresis increases the level of confidence we can have on the results and on the glue behavior in cold environment.

Finally, our optomechanical design for cold optics with diameter close to 180 mm has been successfully qualified for the very demanding space conditions. Accelerate ageing has been simulated with dedicated thermal cycling and the launch constraints have been taken into account in the design. The mechanical qualification of the solution is on going under CNES control.

ACKNOWLEDGMENT

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A numerous of papers have been used as starting point for the design trade-off activity. Among them, the most relevant were :

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