RMs1 – The state of the art SWaP cooler

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ABSTRACT

For five years, Thales Cryogenics has led a new development cycle in order to design and deliver a new generation of SWaP cryocoolers. Both linear and rotary Stirling coolers have been developed.

SWaP coolers are especially designed to cool the emerging High Operating Temperature IR detector (HOT). Insofar as optimal detector performance for HOT technologies are still challenging, Thales forced himself to develop a rotary cooler that can cool detector at intermediate cold temperatures, ie. 90 to 140K, even if the optimal performances are reached for 150K.

A first demonstrator was shown during the SPIE2015 exhibition. That prototype was useful to investigate technologies to be introduced in order to drastically improve the compactness and the weight. Both aspects were reduced by 50% compared to a legacy RM2. The achieved compactness was identified as an optimal trade-off between mass and volume versus the associated production costs.

Last year, Thales worked on new prototypes of the RMs1 SWaP rotary cooler. That product is the results of the previous R&T and design phases, on one hand, and the adoption of generic standards on interfaces like the cold finger in order to simplify integration – and thus reduce overall cost – by our customers on the other hand. Associated performances were presented and commented.

The current paper is focused on the qualification results obtained at the end of 2017. Especially, the available cooling power versus the cold temperature will be shared, next to other important key cryogenics performances such as the cool down time for dedicated detectors, characterized by a thermal masses and operational temperatures. Moreover, a particular effort has been made on other “soft” performances, in order to greatly improve the user experience, that is to say noise and induced vibrations. At last, first lifetime figures for the RMs1 are also presented and commented.

As a conclusion, the compliance of the RMs1 performances with expectations for HOT IR detectors is discussed, in order to highlight the next steps of the development of the SWaP cryocoolers.

Keywords: Cryogenics, Rotary stirling cooler, IR detector, HOT, SWaP

1. INTRODUCTION

Cryocoolers are an essential component of cooled Infrared cameras. Their volume and power consumption are larger than the IR component itself and represent the biggest part of the Integrated Detector Cooler Assembly (IDCA). As a result, a SWaP Hand Held Thermal Imager (HHTI) must necessarily rely on a SWaP cryocooler. SWaP stands for Size, Weight and Power consumption downsizing.

Rotary Stirling coolers are the most compact solutions available. Their Size, Weight and Power characteristics strongly depends on:

- the IR component to be cooled and its associated dewar, in term of thermal mass and thermal losses,
- the cold temperature to be maintained in operating conditions,
- the thermal management of the cooler (ambient temperature)

Over the last ten years, the pixel pitch of the detectors tends to decrease. That is to compensate the increasing number of pixels needed for High Resolution cameras. The overall impact of this trend is towards more powerful and therefore larger coolers. But SWaP coolers have been made possible by the development of new IR components able to operate at high temperature (HOT detectors) [1]. Both XBn and HgCdTe detectors are nowadays able to work above 130K in their HOT versions [2].

Thales Cryogenics has launched 5 years ago a new R&D cycle in order to provide SWaP cooling solutions dedicated to HOT detectors. Both linear and rotary Stirling cooler has been developed. Thales LAS France, formerly known as Thales Cryogénie SAS, has designed and provided rotary Stirling coolers for twenty years. These products constitute the part of the rotary coolers offered by Thales Cryogenics, while linear coolers come from Thales Cryogenics BV, Holland.

The current paper focuses on the performances of the SWaP rotary cooler proposed by Thales. The RMs1 product has been designed to deliver optimal performances within half the volume and half the weight of a RM2 cooler. A first demonstrator was shown during the SPIE2015 exhibition. That prototype was useful to investigate technologies to be introduced in order to drastically improve the compactness and the weight. The cost to further reduce size and weight characteristics are considered prohibitive.

The RMs1 includes these technologies, in addition to strong improvement done to reduce power consumption. Moreover, the RMs1 adopts a generic coldfinger interface designed to simplify integration within the dewar and then to reduce overall cost of the IDCA.

The current paper is focused on the qualification results obtained at the beginning of 2018. Especially, the available cooling power versus the cold temperature will be shared, next to other important key cryogenics performances such as the cool down time or the focal temperature stability for dedicated detectors, characterized by a thermal masses and operational temperatures. Moreover, a particular effort has been made on other performances, in order to greatly improve the HHTI user experience, that is to say, noise and induced vibrations. In addition, the cooler driver electronic characteristics are presented. At last, first lifetime figures for the RMs1 are also presented and commented.

2. SWAP REQUIREMENTS

The various manufacturers of HOT detectors each have differing dewar and detector parameters. At the start of Thales Cryogenics cooler development, a baseline set of parameters was identified. The following generalized set of cooling parameters required for SWaP application was presented during the 2015 SPIE Defense, Security and Sensing exhibition [3] and is reminded in Table 1.

Defining a generalized set of requirements is not obvious, as different FPA manufacturers and technologies have each their own working points. 150K is a common operating temperature defined as a baseline for XBn detectors and is considered as a target for HgCdTe HOT detectors. Even if higher temperature (160-170K) can be quoted in literature [4], the operational applications are hardly visible up to now. Manufacturing process for HOT detector working up to 150K seems to be challenging enough [5] for the coming years. As a consequence, several IR detector manufacturers could consider intermediate HOT detector, with working temperature ranging from 150K down to 120 or 110K while processes maturity is not high enough especially for HgCdTe detectors at 150K.

The RMs1 rotary cooler has been developed with the table 1 requirement as a baseline for requirements. It has then been also designed to provide a relevant cooling solution even for low temperature such as 110K

Table 1: SWaP initial requirements

Operating temperature [K]	150
Total heat load [mW] between 20°C and 77K which includes: - Cold finger wall parasitics - Dewar load (radiative) - Wire load (conductive) - Active load – power dissipated by the detector	160
Thermal mass [J] between 20°C and 77K	100

It has to be mentioned that these three requirements (Size, Weight and Power) are contradictory the one to the other one in a certain way:

- The reduction of the cool down time requires a cryocooler able to deliver the highest possible cooling power. This is in contradiction with keeping an important cooler efficiency in steady state regulation.
- Reducing the cooler size and mass is on one side necessary to reduce all parasitic mechanical losses (friction) inside the cooler but is on the other side critical with regard to motor efficiency.

As a consequence, establishing the correct trade-off between these requirements is far from being trivial. A significant work has been undertaken in order to obtain a cryocooler with high cooling power density for cool down purposes while keeping high efficiency for steady state operation which is a key requirements for battery autonomy in Hand Held Thermal Imagers.

Finally, in order to standardize as much as possible the customer interface, a common cold finger design for SWaP cryocoolers has been defined and agreed between several cooler manufacturers. The RMs1 cryocooler is fully compatible and interchangeable with any cooler fitting in this common cold finger design.

3. GENERAL PRESENTATION OF RMS1

The following paragraph gives an overview of the main characteristics of the RMs1 cooler. All the data provided in this paragraph comes from measurements made on qualification prototypes.

- The nominal input voltage for RMs1 is 12V.
- The RMs1 is designed for performing in a climatic environment from -40°C to +71°C.
- The main dimensions of the RMs1 are presented in the sketch below:

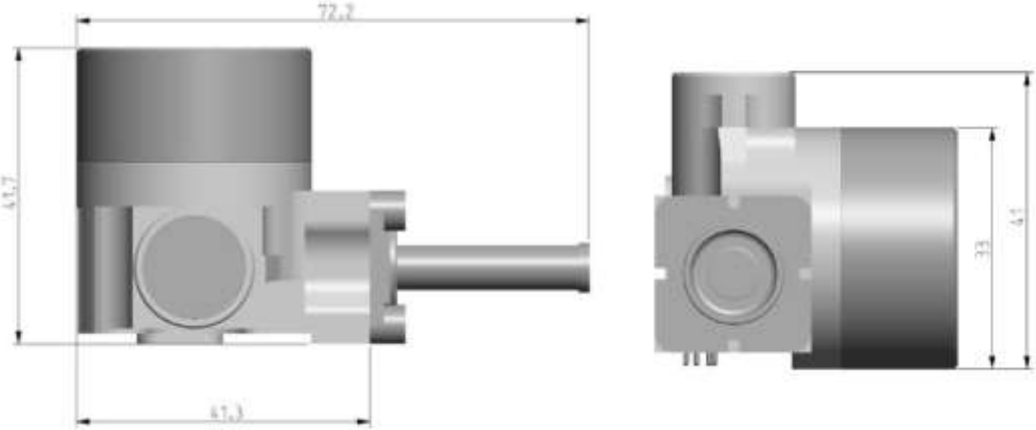

Figure 1: Overall dimensions of RMs1 integrated in common cold finger

Figure 2: Comparison of the legacy RM2 (left), and the RMs1 (right). Its volume is 45% smaller than RM2 one.

The following statement has been previously published [6] and are summarized below:

The reduction in dimensions between the RM2 and the RMs1 represents:

- -50% along motor axis
- -11% along compressor axis
- -25% along cold finger axis

The external volume of an RM2 cooler is 74 cm^3. The external volume of the RMs1 is 40 cm^3. The reduction in external volume between RM2 and RMs1 reaches 45%.

The RMs1 cryocooler mass is 142g. This mass is for the cryocooler only and does not include the dewar nor the driver. For comparison and in a same configuration, the existing RM2 cryocooler used in many handheld applications today has a mass of 275g. This represents a mass reduction of more than 45% between the RM2 cooler and the RMs1 cooler.

The RMs1 filling port is common with the existing range of rotary cryocoolers RM2 and RM4. This enables integrators to use the existing available industrial tooling for the RMs1 cryocooler.

The RMs1 cryocooler is fully compatible and interchangeable with any cooler fitting in the common cold finger design as presented earlier. This allows the integrator to have access to a variety of cryocoolers with the same interface in order to choose the best suited cryocooler for the considered application. Especially, Thales Cryogenics has developed both linear and rotary SWaP solution. The UP8197 is also compatible of this common cold finger [7]. As a result, customers could choose the solution best suited to their applications.

In addition Thales Cryogenics has worked to minimize the reduction of the internal cooler volume while maximizing reduction of the external cooler volume. In that way, the external reduction of the cooler external volume is 45% while the internal volume is similar than previous HHTI cooler (RM2). Besides, RMs1 introduces a new tightness management. Screws and associated flange diameters represent a large part of the volume and mass of the cooler. The tolerable leakage rate has to be reduced in order to avoid refilling maintainability too often. Indeed, for an equivalent leakage rate, the internal pressure should reach a critical lower limit faster than bigger coolers. For both these reasons, Thales Cryogenics has considered a welded outer shell.

As a result, only two remaining dismountable seals are present on RMs1. The interface with dewar is dismountable for integration purposes. The helium tightness at that interface is ensured thanks to a metallic seal located in a groove enabling reproducible helium tightness and detector positioning. The filling port is also sealed with a dismountable seal to enable detector-cooler assembly to be filled with working gas after integration. These two seals are already validated and fully mastered on legacy cryocoolers. The likelihood of leakage is reduced accordingly.

The resulting product is show in Figure 3. The removal of screws gives a robust and compact design to the RMs1.

4. PERFORMANCES OF RMS1

In the next chapter, figures are average values coming from tests performed during the qualification of the product on 6 coolers and 5 drivers.

Figure 3: RMs1 prototypes, integrated in a dewar thermal mock-up

4.1 Weight

The weight of the cooler may have both direct and indirect impacts on the final product weight. For instance a reduction of the weight could lead to a reduction of the system weight but also in an increase of the battery capacity if the associated effect is an increasing power consumption (cf. section 2).

The cooler weights 142 gr without dewar nor protector. A cooler driver electronic (CDE) is required to drive the cooler. The CDE weights 15 gr. Finally the equipments cooler and driver weights 157gr.

The weight of the cable between the cooler and driver is not included in the previous number. In a standard version, 10 gr shall be added to take into account the cable weight. That mass may still change, insofar as the connecting cable weight greatly depends on the length and the shield level required for the application.

Up to now, we can therefore consider that the mass of the cooling function insured by a RMs1 remains below 175gr in most usual application. That weight represents between 6 and 9% of the new generation of Hand Held Thermal Imager (HHTI) expected weight. As a comparison, the RM2 weights 275gr within HHTI around 3.5kg, equivalent to 8% of the total weight. Both SWaP cooler and imager have lost weight in proportion.

4.2 Cryogenic performances

The performances presented in this paragraph are related to a dewar in line with initial requirements (see Table 1). The main parameters for all the values are the following: input voltage to the cooler driver electronics: 12V and operating temperature: 150K.

The power injection at the cold tip is done to simulate the actual losses of the IR component itself when operating.

- *Cool down time:*

The Figure 4 represents the typical cool down time measured as a function of the nominal ambient temperature. At a nominal operating temperature of 150K, the cool down time at room temperature is about 2min. At +70°C ambient temperature, the cool down time is about 2min30. The Figure 5 represents the cool down time variation for several prototypes at 20°C of ambient temperature and 150K.

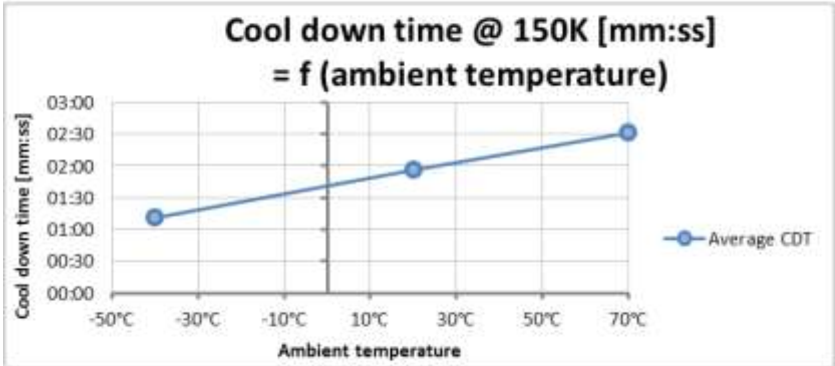

Figure 4: Cool down time as a function of ambient temperature

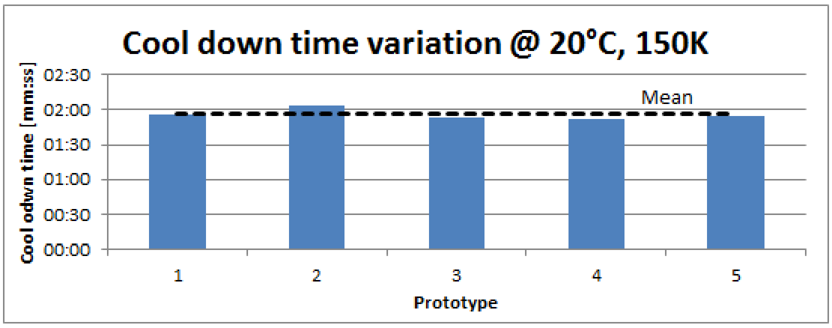

Figure 5: RMs1 cool down time variation for prototypes

After manufacturing several cooler, it can be said that the cool down time variation are very low. For 5 prototypes, the mean is at 1min56 and the standard variation is about 5s.

In a standard operation, the HHTI equipped with an RMs1 is then able to provide a stable image within 2min. Such a short duration seems to meet application needs in most of the cases. It is also a major improvement compared to legacy coolers

For applications requiring shorter time to operation, one can still consider internal adjustments leading to a few seconds shorter duration. Standby mode can also be implemented. The cooler runs at low speed to keep the IR cold plate at an intermediate temperature and have a limited power consumption. The time needed to reach the operating temperature can then be adjusted and will result in a trade-off between the time to operation and the power consumption in standby mode.

- *Input power in regulation:*

The Figure 6 represents the typical input power measured at the cooler input and at the driver input in steady state operation as a function of the cold temperature setpoint; and for two different ambient temperatures.

Moreover, the Figure 7 represents the typical input power measured at the cooler input and at the driver input in steady state operation at 150K as a function of the ambient temperatures.

Finally, the Figure 8 **Erreur ! Source du renvoi introuvable.**represents the input power measured at the cooler input in steady state operation at 150K as a function of the ambient temperature and the total cooling power (that is to say including the thermal losses of the dewar itself).

In addition to the presented figures, the input power at the entrance of the cooler has also been monitored. At room temperature, and for a nominal cold temperature of 150K, the power consumption of the cooler alone is only 1W.

One can also notice than the DC power consumption remains below 2W at room temperature, and reaches 3.5W at 71°C. That power remains quite far from the maximum input power available: the cooler is far from running at maximum speed. This power margin guarantees a good reliability even at high temperature.

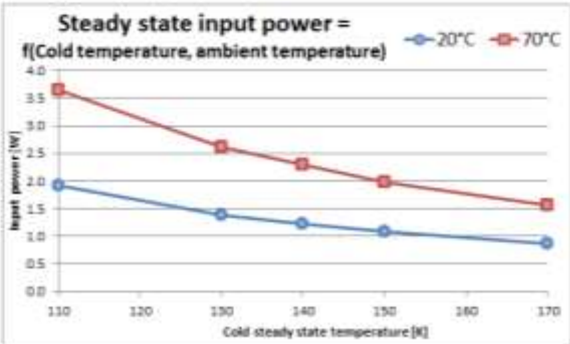

Figure 6: Steady state input power as a function of cold temperature and ambient temperature

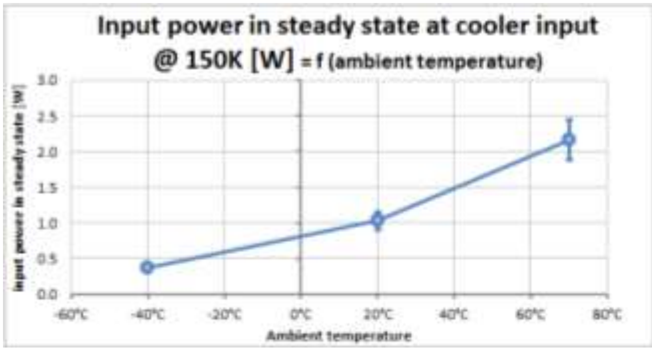

Figure 7: Steady state input power at 150K as a function of ambient temperature

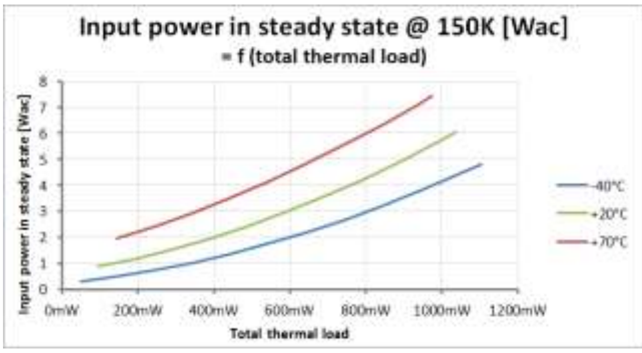

Figure 8: Steady state input power at 150K in function of ambient temperature and total cooling power

Besides, bigger components with large matrix array can also be cooled with an RMs1 unit, insofar as this cooler is still able to provide 1W of cooling in a steady-state mode at 150K and room temperature.

- Total cryogenic capacity

The Figure 9 presents the measure of the total cryogenic capacity of the cooler, including the thermal losses of the dewar itself.

The total cooling power is close to 1 W whatever the ambient temperature. That's mean, the cooler is able to cool huge dewar at 150K. Large total cryogenic capacity available is also needed when the operating focal plan temperature could be lower than 150K.

Especially, HgCdTe NETD is known to be difficult to stabilize especially with HOT technologies [8]. With the current cryogenic capacity of the RMs1 cooler, one can implement intermediate modes where the IR component temperature could be lowered down to 110K or below. Such a running mode will provide ultimate NETD, as soon as the EO performances are critical. The drawback will be a rise of the power consumption as shown in Figure 8.

4.3 Focal temperature stability

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Table 2 and Table 3 show the variations of cold temperature and associated input power (DC) at 150K. The stability is the difference between the min and max value during 10 minutes of continuous regulation.

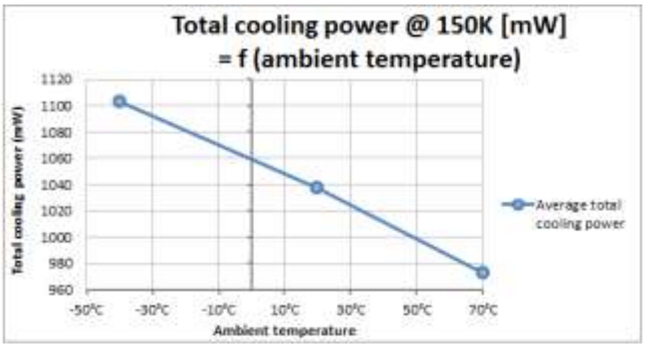

Figure 9: RMs1 total cooling power at 150K in function of ambient temperature

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Table 2: Impact of input voltage and ambient temperature

Ambient temperature (°C)	Input voltage (Vdc)	Cold temperature variation (K)	Δ Input power btwn min and max (Wdc)
20	12	< +/- 0.01	< 0.06
	8	< +/- 0.01	< 0.10
	16	< +/- 0.01	< 0.09
-40	12	< +/- 0.01	< 0.07
	8	< +/- 0.01	< 0.07
	16	< +/- 0.01	< 0.06
70	12	< +/- 0.01	< 0.15
	8	< +/- 0.01	< 0.11
	16	< +/- 0.01	< **0.16**

Table 3: Impact of cold steady state temperature (nominal voltage, 12V)

Ambient temperature (°C)	Cold steady state temperature (K)	Cold temperature variation (K)	Δ Input power btwn min and max (Wdc)
20	170	< +/- 0.01	< 0.06
	150	< +/- 0.01	< 0.08
	140	< +/- 0.01	< 0.07
	110	< +/- 0.01	< 0.10
-40	170	< +/- 0.01	< 0.08
	150	< +/- 0.01	< 0.07
	140	< +/- 0.01	< 0.06
	110	< +/- 0.01	< 0.08
70	170	< +/- 0.01	< 0.08
	150	< +/- 0.01	< 0.09
	140	< +/- 0.01	< 0.13
	110	< +/- 0.01	< 0.11

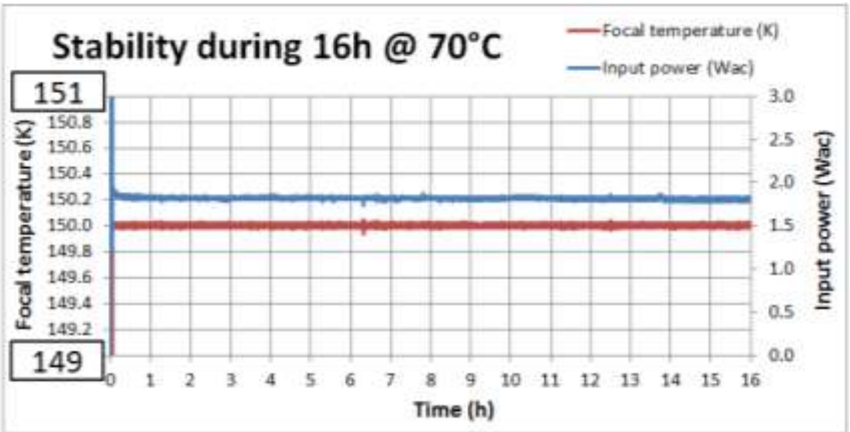

Figure 10: Temperature and input power stability during 16 hours at 70°C. the full scale is +/-1 Kelvin for focal temperature and 0-3W for input power.

From tables 2 and 3, it appears that whatever the conditions, the cold temperature variation and the input power variation are very stable. Firstly, for the cold temperature, the variations during 10minutes are always below 0.01 K. Secondly for the input power, the delta during 10 min are all below 0.16 W. Whatever the conditions, the RMs1 cooler is able to provide very precise thermal regulation, below 10mK. Such a good result is linked to the cryogenic capacity which is high enough to ensure a regulation far from the actual limits of the cooler.

Even if stability criteria are given over 10min, one can also underlines that the tests runs during more than 16 hours at 70°C ambient temperature. During the whole test, the variations do not exceed 0.4 K and 0.15Wdc (refer to the Figure 10).

4.4 Induced vibrations

With regard to the management of the integration of the cooler in the host system, one of the important aspects is the level of vibrations induced by the cooler operation. These vibrations have to be mastered in order to avoid two issues at system level:

- Awkward movement of the optical axis leading to a blur of the resulting image,
- Generation of acoustic noise by the system when excited by the cooler induced vibrations.

The RMs1 has been specifically designed to minimize the generated induced vibrations.

A homemade setup has been developed for the last five years to evaluate the induced vibrations. This set up is today used for improving our products performances as well as for developing the new products. RMs1 has benefited from all latest improvements in that field. This approach results in a decreased level of induced vibrations for RMs1 compared to our existing range of coolers.

The Figure 12compares the induced vibrations measured for several coolers. The comparison is made on the three cooler axis (designed as compressor axis, cold finger axis and motor axis, refer to the Figure 11). For these measurements, all coolers are running at the same rotation speed in order to be able to compare intrinsic cooler performances.

Moreover, the RM2 global level is added to the comparison. The spectra from RM2 have been obtained on one RM2 product representative of the last two years of production. That is to say this RM2 design already includes design improvements for vibration reduction. Especially, an internal project has shown that the current level monitored on RM2 is compatible of demanding application like the gauge required for gimbals (airborne application).

With this comparison, it can be seen that the RMs1 generates much less induced vibrations than RM2 cooler. Furthermore, the global levels are similar between all RMs1 coolers. One can infer from these results that the design and the associated manufacturing processes may lead to a very stable production. All the RMs1 may be used for applications requiring extremely low induced vibration like airborne applications. Coupled with its compactness and its power capacity, RMs1 may be a very relevant cooler for long-range infrared imagers implemented in mini gimbal applications.

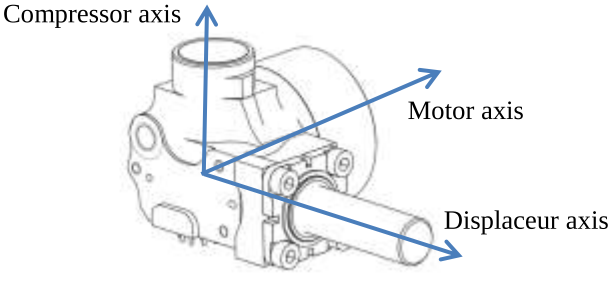

Figure 11: Induced vibrations axis

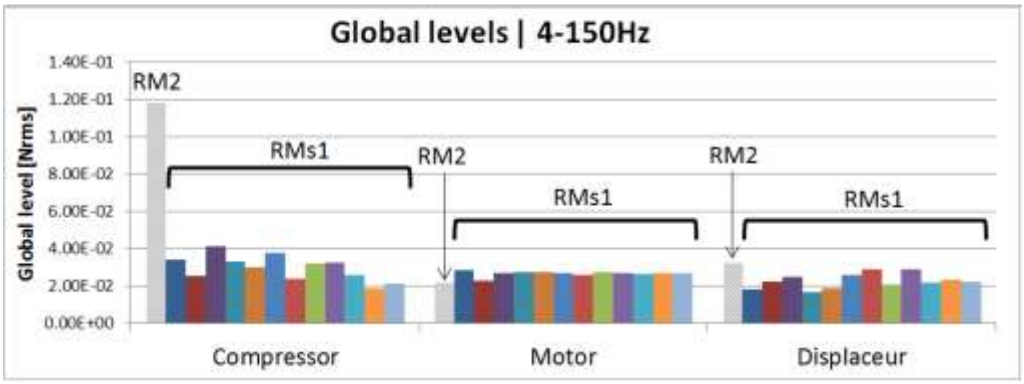

Figure 12: RMs1 global induced vibrations levels and comparison with RM2

4.5 Acoustic noise

With regard to the management of the integration of the cooler in the host system, one of the important aspects is the level of acoustic noise generated by the cooler operation. The main application for SWAP product is for Hand Held Thermal Imager (HHTI). For this kind of application, the detectability of the equipment is a major issue.

The Figure 13 represents the results of the measure performed according to MIL-STD-1474 – non-detectability test. 8 microphones are located around the cooler and used in a semi anechoic room. The cooler runs at speed for a regulation at 150K.

The RMs1 unit which has been tested is silent at 10m in a steady-state mode at 150K. At 3150Hz, the level is quite close to the non-detectability at 10m. The capability of serial production may be evaluated to confirm these results. On the other hand, this level can still be improved by working on the integration of the cooler in the system.

The global sound power level according to ISO3744 is 43 dBA.

The RMs1 has been specifically designed to minimize the generated acoustic noise. A comparison can be done with another SWaP cooler available on the market [9] for the same conditions (measure according to MIL-STD-1474 at 1m, see Figure 14).

At 1m, the global level of the RMs1 is 32 dB whereas the global level of the other SWaP cooler is 33.8 dB.

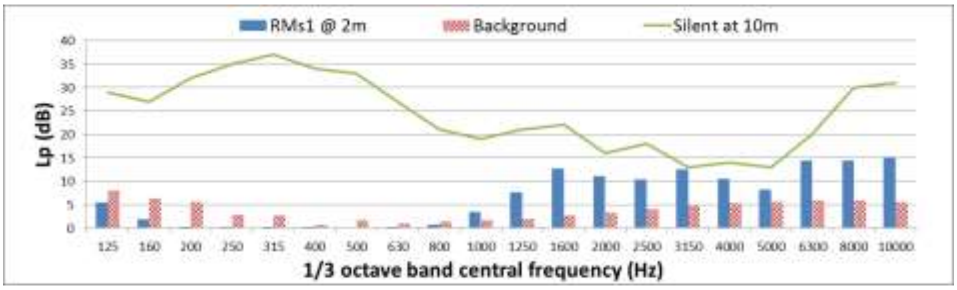

Figure 13: Non-detectability measure in steady state

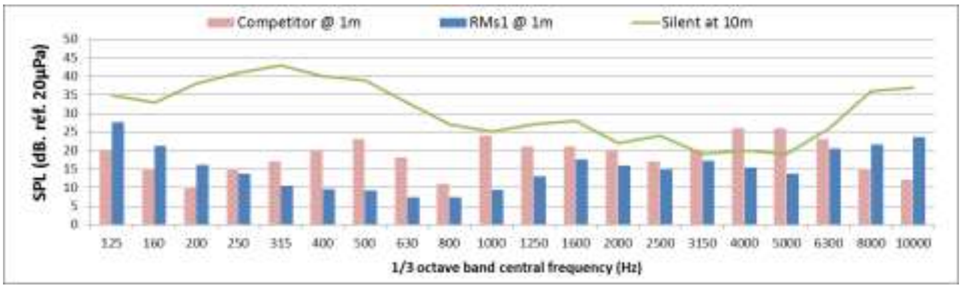

Figure 14: Comparison of RMs1 acoustic noise with competitor

4.6 Mechanical environment

The possible applications for a cooler are very large (portable, vehicle, airborne…). The mechanical environments sustained by the cooler with all these applications are very different. In order to qualify the product for the widest application range, a maximum spectra is defined and applied to the cooler and driver. That spectra includes the most demanding application (airborne) in term of mechanical vibrations and shocks sustained by the cooler.

- Vibrations

The following profiles with the cooler not operational were applied to the cooler and driver:

- Sine and random vibrations

Table 4: Sine vibration profile 10 sweeps at 1 octave/min per axis, 3 axes

Frequency (Hz)	10	58	58	2000
Amplitude (mm)	0.75	0.75	0.74	6.21E-04
Acceleration (peak) (g)	0.30	10.1	10	10

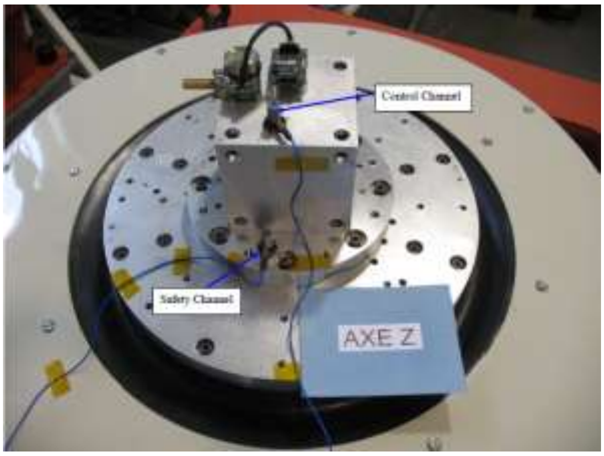

Figure 15: vibration test bench

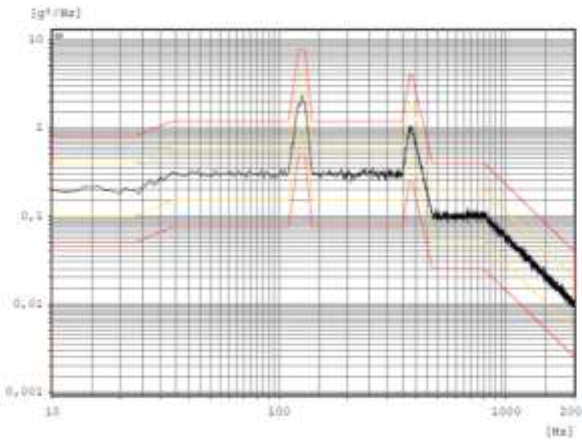

Figure 16: 16 g rms random vibration profile 16 g rms, Duration: 1 hour/axis, 3 axis

Table 5: 16 g rms random vibration profile

Frequency (Hz)	Level (g²/Hz)	Frequency (Hz)	Level (g²/Hz)
10	2.00E-01	245	0.3
23	2.00E-01	350	0.3
34	3.00E-01	375	1
110	3.00E-01	385	1
122	2	475	0.1
130	2	800	0.1
140	0.3	2000	1.00E-02

- Shocks and bumps

The following shocks and bumps are applied to the cooler and driver. The equipment are not operational during the tests.

- Shocks :

  Halfsine shock 50g, 11ms duration, 3 shocks per axis and per direction

  Halfsine shock 40g, 18ms duration, 3 shocks per axis and per direction

  Halfsine shock 100g, 6ms duration, 3 shocks per axis and per direction

- Bumps :

  Halfsine bump 40g, 6ms duration, 1000 bumps per axis and per direction

- Check after tests

Between each axis or profile, a verification of the equipment performances is performed. No variation of performances are measured after all the mechanical tests. The acoustic noise, induced vibrations and cryogenics performances are similar before and after the tests. Up to know, we may consider that the RMs1 cooler could be qualified for airborne application from a mechanical point of view.

5. COOLER DRIVER ELECTRONIC

A new generation of numeric electronic driver is developed for RMs1 driving. The name of this Cooler Driver Electronic (CDE) is DE0009.

Figure 17: Cooler RMs1 and CDE DE0009

The main functions of this CDE are:

- Motor phases management.
- Temperature regulation according to thermal sensor information.
- Analogic interfaces (stand-by / Shut-down / Cooler ready).
- Hours counter.
- Safety functions (input current limitation, micro power cut protection, reverse polarity protection, over temperature protection, over voltage protection).
- EMC filter in order to minimize the emitted perturbations or the susceptibility of the equipment.
- Numeric communication through an RS422 interface
  The communication interface allows to set up the driver but also to have information about the CDE and cooler operations (error code, performance of the cooler, maximum environment seen by the CDE and cooler,…).

The driver is fully qualified for the same environment than the cooler. Moreover it has been designed in order to be able to driver most of Thales RMx cooler

The typical CDE input power is below 0,75 W when the communication is activated and below 0,65 W when the communication is not activated (cooler in steady state at 150K).

6. BALANCE BETWEEN POWER CONSUMPTION AND WEIGHT

SWaP considerations at imager and at cooler level do not have the same impact. Indeed, a trade-off has been explicated last year between the power consumption of the cooler and the total weight of the thermal imager, including the associated batteries [6].

Here is provided a comparison between the RMs1 weight and the weight of other Thales products used on Hand Held Thermal Imager.

Considering works on prototypes previously done [3], we can consider that going further in weight and volume reduction will result in an increase of the power consumption. This is mainly linked to the motor yield which will be negatively impacted within smaller volumes. In order to evaluate if the design solution is optimal at system level, we propose to consider the power to weight ratio induced by batteries [7].

This approach of power to weight ratio was summarized on the following graph [7]. We can now add on this graph the ratio achieved with the RMs1 cooler.

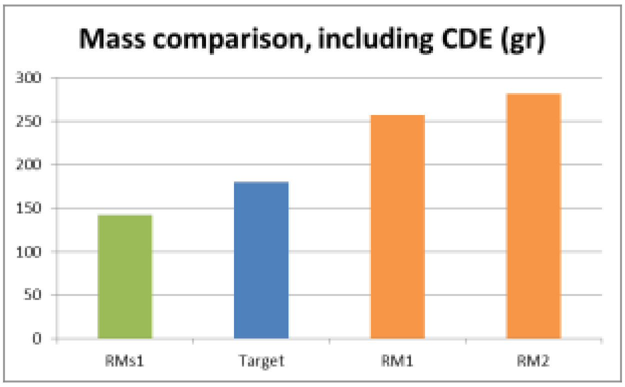

Figure 18: Weight comparison of RMs1 with RM1 and RM2. The mass includes driver electronics weight

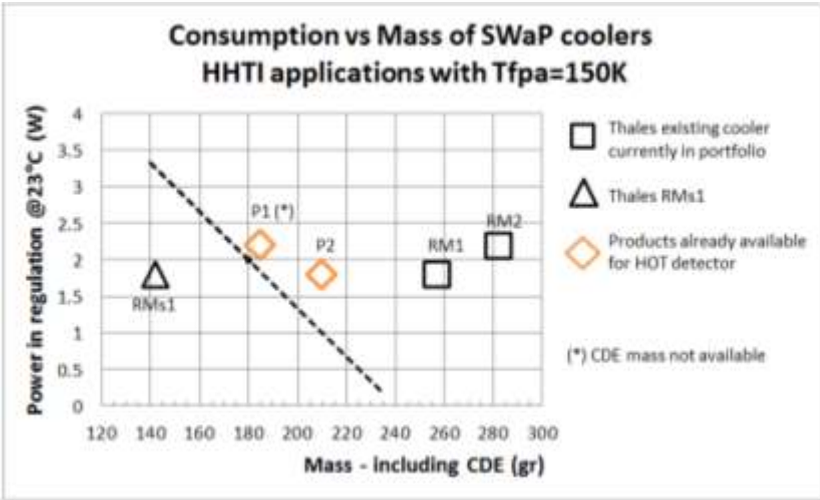

Figure 19: Trade-off between Weight and Power driven by battery specific power at HHTI level. The bold line is based on a 2WDC consumption for 180gr at 150K (Initial target). The slope of the bold line shows an example of specific power. The sensitivity expressed by the bold line slope is based on following assumptions: a specific power of 200W/Kg (Lithium-Ion Battery) and autonomy of 4 hours. The sensitivity of the system is typically of 30gr/W [7]

The products P1 and P2 reported on Figure 19 are commercial coolers designed for HOT applications [10] [11].The dotted lines express then equivalent performances to RM1 and RM2.

As soon as the battery efficiency is known, all of the coolers located on the bold line will have the same impact on HHTI global weight. If we consider an expected SWaP configuration, one can see that RM1 and RM2 are too heavy to be an optimal solution for optimized HOT detector operating at 150K or above. Nonetheless, these products should still be considered to provide higher cooling powers, for larger HOT detectors for instance.

The RMs1 can then be considered as a better optimum than the target, and constitute up to now the cooler with the best power to weight ratio in the SWaP segment.

7. LIFE TIME RMS1

In order to evaluate reliability in an operational profile mission, one have to consider the environmental stresses, the number of hour, the focal plane temperature, the number of storage hours. Thales Cryogenics uses to communicate on the reliability in a standard profile called STP profile. And MTTF are evaluated in a dedicated accelerated profile which is called A20 profile. The latter has been designed to run continuously at high speed and acceleration factors has been established between A20 and operational profile [12].

It must be mentioned that this profile designed for existing coolers remains also relevant for the RMs1 cooler. Indeed, RMs1 rotation speed in steady state operation in a typical application is similar to the rotation speed in steady state for the existing Thales coolers.

Today, several coolers are in lifetime tests. The Figure 20represents the intermediate checks performed for the two oldest coolers. These coolers are still running. Both coolers run for more than 3000 hours in A20. The parameters checked regularly do not show any variation. These results allow us to prove a reliability of 10,000 operating hours in representative customer application.

Today, results are not yet enough to prove the targeted reliability of more than 15,000 operating hours in representative customer application. But for years, Thales is working on reliability tests, reliability growth on existing products and on reliability assessment during design phase [13]. A good correlation has been demonstrated between the reliability assessment during design phase and operational results in our accelerated life time cycle or in customer operation in the field [14]. Moreover, the RMs1 design takes advantages from feedback obtained on other legacy products like RM2. The latter shown currently MTTF higher than 40,000hr. As a consequence, Thales is confident that the RMs1 will demonstrate the targeted reliability before the end of the year (15,000hr). The actual MTTF could be even higher than that and the RMs1 is expected to be in the same class of reliability than RM2.

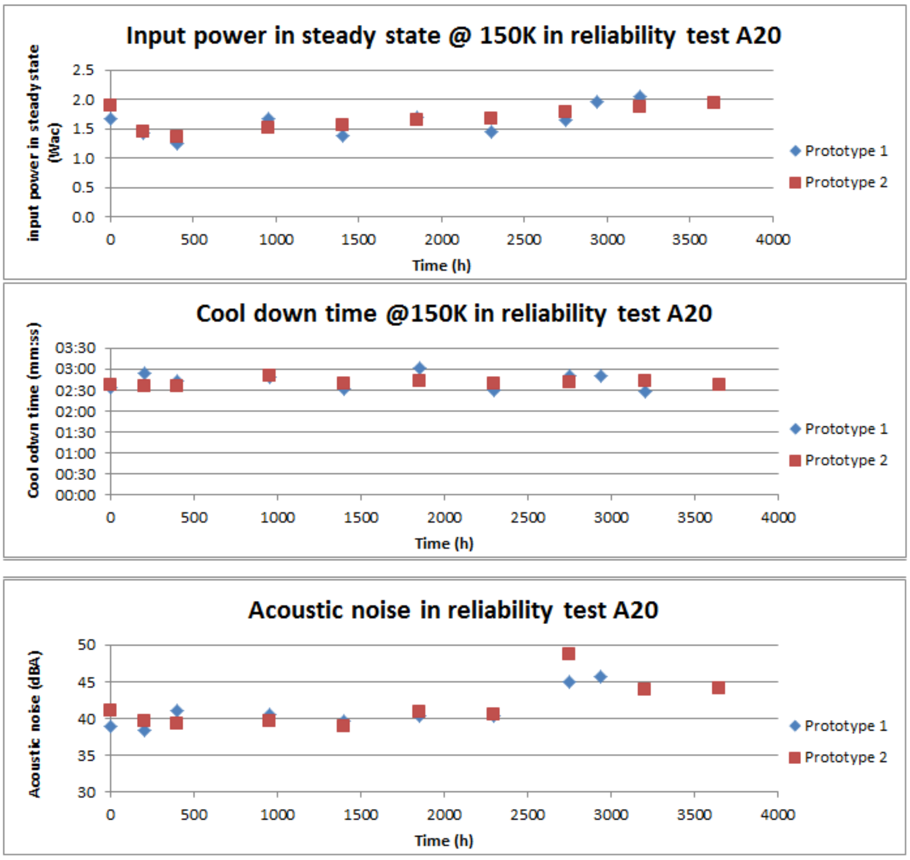

Figure 20: Lifetime test intermediate checks

8. CONCLUSION

Last year, we introduced the first characteristics measured on RMs1 prototype. The current paper has updated these results with qualification data. The figures are especially obtained on a larger number of units, leading to a better estimation of discrepancy and average values.

It has been proven the RMs1 is a relevant SWaP solution. First, the Size, Weight and Power consumption of cooler has been drastically reduced. But one can also consider that cooler as a SWaP enabler at system level. The power-to-weight ratio is well below the initial target. That is to say that for a lighter weight than other coolers, the thermodynamic yield of the cooler is high enough to authorize either lighter batteries, either longer autonomy of HHTI.

The RMs1 could be considered as a breakthrough in the SWaP cryocooler range. The RMs1 offers a differentiation in the Swap domain compared to other marketed product and delivers a great value to applications where SWaP criteria and cool down time are of importance. The design choices have also led to a low vibration product, with induced forces significantly lower than the current RM2.

Within half the size and less than half the weight of an RM2, the typical performances of the RMs1 are:

- Cool Down Time : can reach 150K in less than 2min30 at 71°C
- consumes 1W to regulates at 150K at room temperature (1.8WDC)
- has a cryogenic power of more than 1W at 150K, and can then operate at 110K and below
- induces very low level of force at the interface (below 40mNrms [4-150 Hz])
- is expected to have a MTTF higher than 15,000hr. 10,000 hours has been proven up to now.

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