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THERMAL BEHAVIOUR OF A MICROSATELLITE
THE µSat-1 IN-FLIGHT EXPERIENCE

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Abstract. µSat-1 "Víctor" *is a 32-kg, 350*350*450 mm, 3-axis controlled, earth imaging microsatellite, intended for development, qualification and testing of low-cost space technologies; program began in September, 1992, being launched August 29th, 1996 into an elliptic, 245*1200 km, 62*^{o}*inclination orbit, by a* ***Molnya*** *launcher, as a secondary payload. It became the first argentine-made satellite, performing according to mission requirements up to date, almost three years later.*

This paper presents a study about the thermal behaviour of the satellite during its life, as seen through flight telemetry data. As most microsatellites, ***"Víctor"*** *presents a particular flight profile, which consists mainly in a random, free - attitude movement during most of flight time, being three-axis controlled only when it is at earth station range, condition that occurs twice or, at most, four times a day, for periods of ten to fifteen minutes each one. Moreover, temperature data are taken only on earth station requirement, not in a continous sampling mode.*

Due to these operating features, a stochastic analysis of flight data was preferred, which proved to be more useful than the deterministic temperature assesment normally performed in bigger, well-known attitude satellites. Results obtained during operation from November 1996 to July 1998 are presented, as well as considerations about the stochastic analysis performed and conclussions, which represented great aid in the thermal design of ***µSat-2****, the second satellite of the series, to be launched during last quarter of 1999.*

Keywords: *Microsatellite, Thermal Control, Stochastic Analysis*

1. INTRODUCTION

µSat-1 "Víctor" was conceived to be a benchtest for development of low-cost space technologies (Brito & Murgio, 1996; Zapico *et al*, 1996; Palacio & Ferreyra, 1998), under a 4 year, 1 million-dollar program financially backed by Government of Province (State) of Córdoba. Its development began in September, 1992, being launched August 29th, 1996, into an elliptic, 245*1200km, 62^{o} inclination orbit, by a **Molnya** launcher, together with **Prognoz** and **Magion-5**

satellites (both part of **Interball-2** mission). Since then, **µSat-1** has been functional, giving us a valuable experience about pros-and-cons of this approach.

In this paper we present results obtained by analysis of thermal data provided by telemetry system; giving the characteristics of the mission, we considered that a stochastic treatment should be better than the classic deterministic one, used in bigger, fixed attitude satellites.

This analysis allowed us to verify design concepts, as well as to detect and take corrective actions to malfuctions that occured. Also, telemetry improvements neccesity became evident for future developments.

2. DESCRIPTION OF THE SATELLITE

Víctor is a 3-axis stabilized microsatellite oriented to earth imaging; main characteristics include:

- 32 kg, 350*350*450 mm
- Two CCD, 700*500 pixels, pancromatic cameras (wide FOV, 2000*1500 km., and narrow FOV, 70*50 km)
- Two-band uplink (UHF and S band) and three-band downlink (VHF, UHF and S band)
- Three-axis stabilization, via reaction wheels and magnetic coils.

Víctor structure consist in 3 honeycomb plates, housing all subsystems, covered by a monolitic Al cowl, which supports four 88 Si cells solar panels (Fig. 1, Fig. 2).

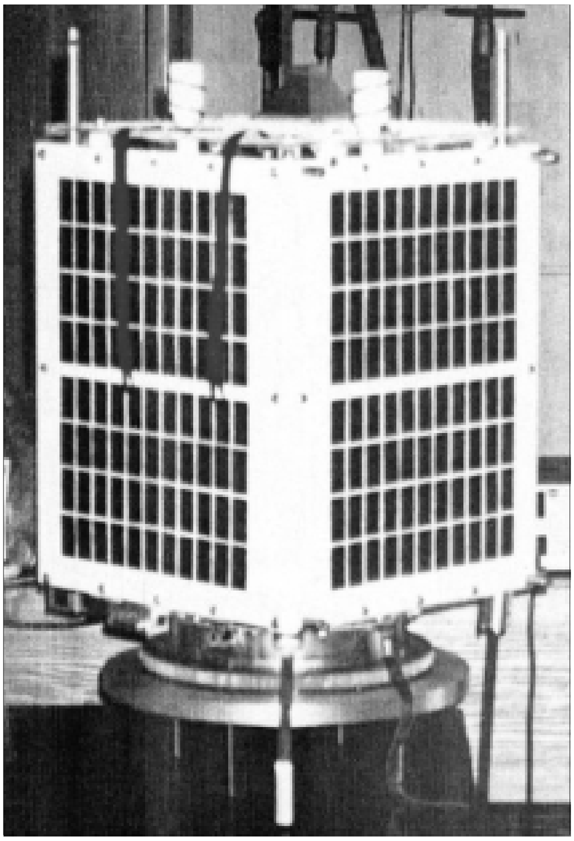

Fig. 1. µSat-1 external view

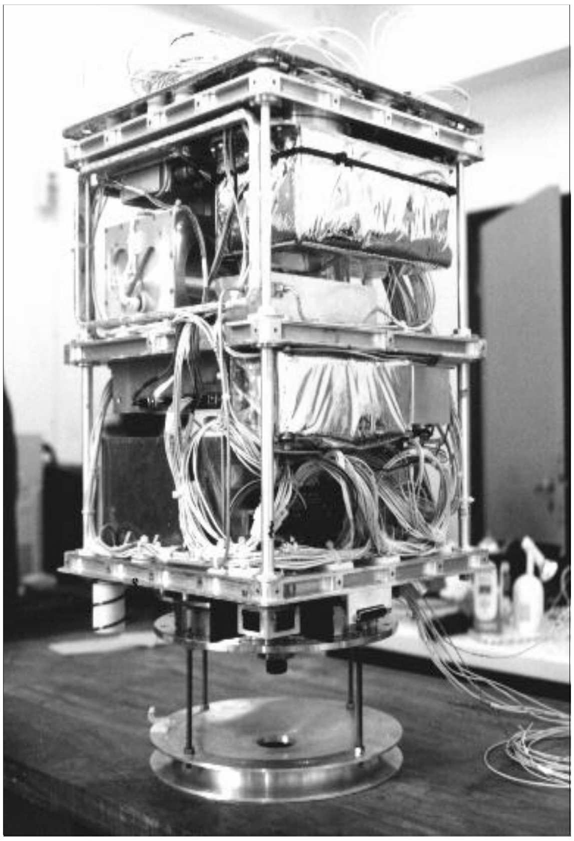

Fig. 2. µSat-1 internal view

Since, as in most microsatellites, costs and simplicity precludes use of active thermal control systems, structure itself fulfill the heat conduction mission, in order to mantain the required thermal environment.

3. INSTRUMENTATION AND DATA ADQUISITION:

3.1. Instrumentation

µSat-1 is equiped with 11 temperature sensors (thermistors), which main characteristics are seen in table 1:

Table 1 - Temperature Sensors

Parameter	Location	Type	Temp. Range [C]	Status
TPan1	Solar Panel 1	Thermistor	-25/+50	Operative
TPan2	Solar Panel 2	Thermistor	-25/+50	Operative
TPan3	Solar Panel 3	Thermistor	-25/+50	Operative
TPan4	Solar Panel 4	Thermistor	-25/+50	Operative
TCpu	On-Board CPU	Thermistor	-25/+50	Out of Service
TPlat	Inner Plate	Thermistor	-25/+50	Operative
TTxS	S-Band Transmitter	Thermistor	-25/+50	Operative
TTxU	UHF Transciever	Thermistor	-25/+50	Out of Service
TBatt	Battery Pack	Thermistor	-25/+50	Operative
TBatt	Battery Charger	Thermistor	-25/+50	Operative
TPwSr	Power Source	Thermistor	-25/+50	Operative

Due to malfunction of two thermistors, produced during launch, only nine temperatures could be measured; however, these still allowed to obtain a good assesment of temperature distribution of the satellite.

3.2. Data Adquisition

Data adquisition is performed through the telemetry system (which transmits via UHF channel), on request of earth station. No requirement was issued to measure temperatures in a continuous mode, thus we lack of an entire-orbit temperature assesment. This characteristic, which was not seen as a draw-back at time of **µSat-1** development, will be changed in future spacecrafts.

Moreover, an overheating of the battery pack, produced early in orbit, left the satellite short of power, allowing normal operation only during zero-eclipse periods (roughly 10-15 days each

3 or 4 months). Although this problem allowed to obtain data mainly during “hot” orbits, some data were obtained with up to 25 minutes of eclipse time, allowing us to have an insight to the “cold” thermal condition.

Routinely, during each operating pass, at least one telemetry is requested; data are downloaded into an ASCII file, which includes date and time up to seconds, for further analysis. These data were which we used.

4. DATA ANALISYS:

Between Nov 3rd, 1996 and July 21st, 1998, 275 temperature values were obtained for each measurement point, configuring the database we used for our analisys.

Due to the above explained features, an stochastic approach was preferred instead of the deterministic one; usual axioms and definitions were used (Papoulis, 1965). Statistical data were presented both in “box-and-whiskers” and table forms; in “box and whiskers” graphs boxes represent 25, 50 and 75 percentiles, covering whiskers the rest of the normal data (battery overheating appears as dots outside corresponding whiskers). Notches around the median of the data in each box represent the Standard Deviation of the Mean.

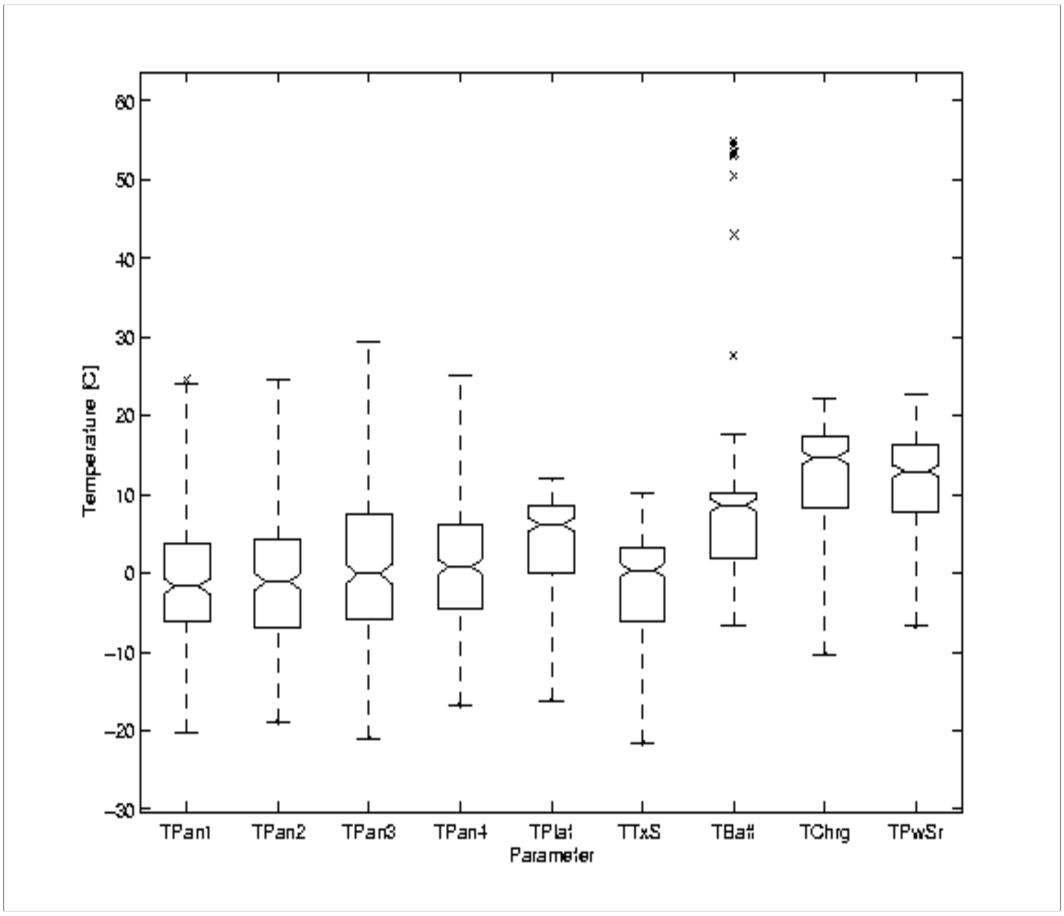

Fig. 3. - Satellite Temperatures from Nov/96 to Jul/98

Figure 3 resumes these statistics:

Same parameters may be seen also in the following table:

Table 2 - Measurement Statistical Parameters

Sensor	Min.	Max.	Q1	Median	Q3	Mean	Sigma
TPan1	-20.14	24.51	-6.23	-1.66	3.68	-0.53	8.48
TPan2	-18.88	24.57	-6.79	-1.10	4.21	-0.38	8.57
TPan3	-20.98	29.29	-5.81	-0.09	7.56	1.74	10.46
TPan4	-16.79	25.09	-4.61	0.81	6.19	1.60	8.52
TPlat	-16.18	12.02	0.05	6.15	8.64	3.58	6.57
TTxS	-21.57	10.27	-6.21	.39	3.16	-1.68	6.69
TBatt	-6.69	54.82	2.03	8.64	10.27	8.31	10.40
TChrg	-10.34	22.25	8.28	14.68	17.40	12.39	6.86
TPwSr	-6.69	22.62	7.76	12.98	16.26	11.18	6.58

From simple observation of Fig. 2 it is possible to distinguish different behaviours of external (Tpan1, Tpan2, Tpan3, Tpan4), and internal temperatures; this fact was veryfied computing the correlation matrix, which results:

Table 3 - Correlation Coefficients Between Temperature Measurements

	TPan1	TPan2	TPan3	TPan4	TPlat	TTxS	TBatt	TChrg	TPwSr
TPan1	1	.257	-.226	.376	.463	.485	.15	.553	.492
TPan2	.257	1	.498	-.214	.545	.633	.328	.590	.446
TPan3	-.226	.498	1	.185	.499	.405	.215	.528	.387
TPan4	.376	-.214	.185	1	.445	.257	.123	.502	.490
TPlat	.463	.545	.499	.445	1	.840	.567	.936	.926
TTxS	.485	.633	.405	.257	.840	1	.327	.842	.669
TBatt	.15	.328	.215	.123	.567	.327	1	.472	.610
TChrg	.553	.590	.528	.502	.936	.842	.472	1	.885
TPwSr	.492	.446	.387	.490	.926	.669	.610	.885	1

Strong correlation coefficients (from .669 to .936) between internal parameters (except **Tbatt**) became evident, which suggest a good thermal coupling between inner components of the satellite.

In order to show that coupling in a more explicit way linear regression estimations are presented for each internal temperatures vs. Tplat:

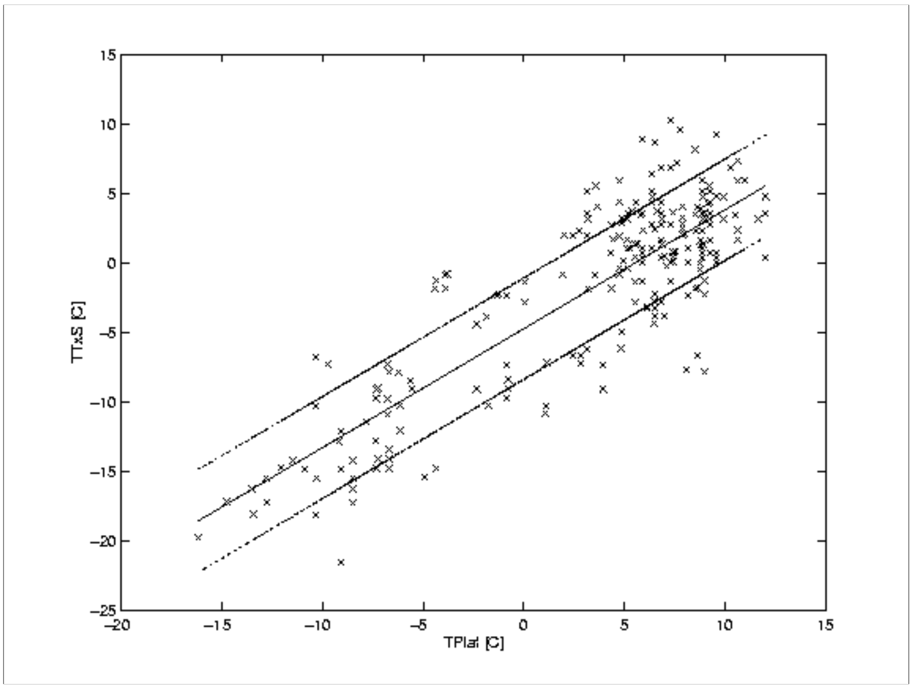

Fig. 4 - TTxS vs. Tplat (Corr = 0.840)

Figure 4 shows a definite linear tendency, in spite to the fact of the dispersion observed, which is explained by the location of the S-band transmitter (in the upper plate, near the exterior of the spacecraft)

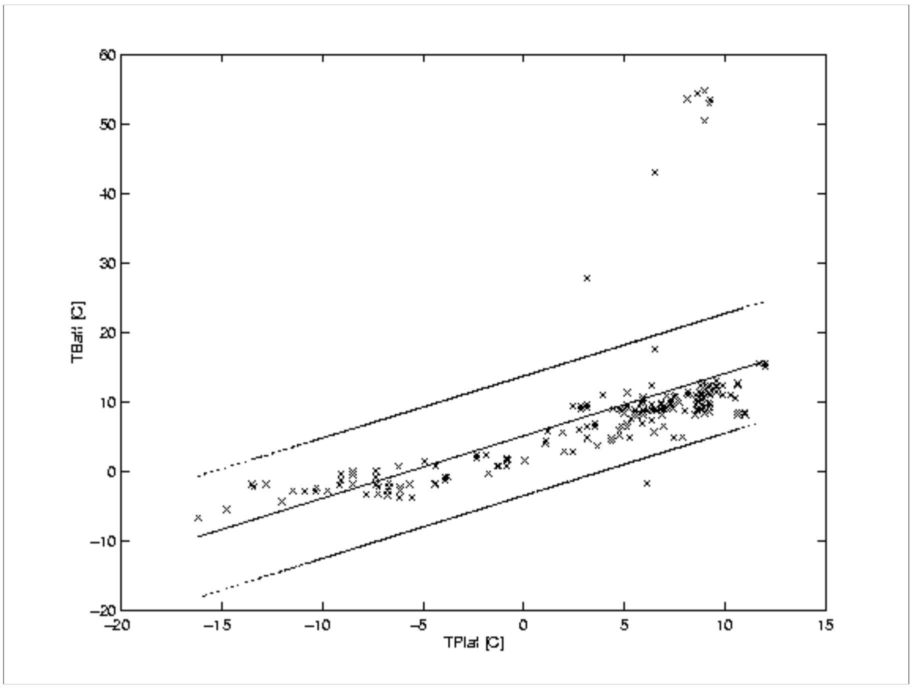

Fig. 5 - TBatt vs. Tplat (Corr = 0.567)

Figure 5 higlights the effect of the battery overheating; most of data follow a well-defined linear tendency, while high battery temperatures are not reflected in plate ones; it suggests that thermal coupling between both is not able to evacuate heat produced during this failure, leading to a reconsideration of battery pack redesign.

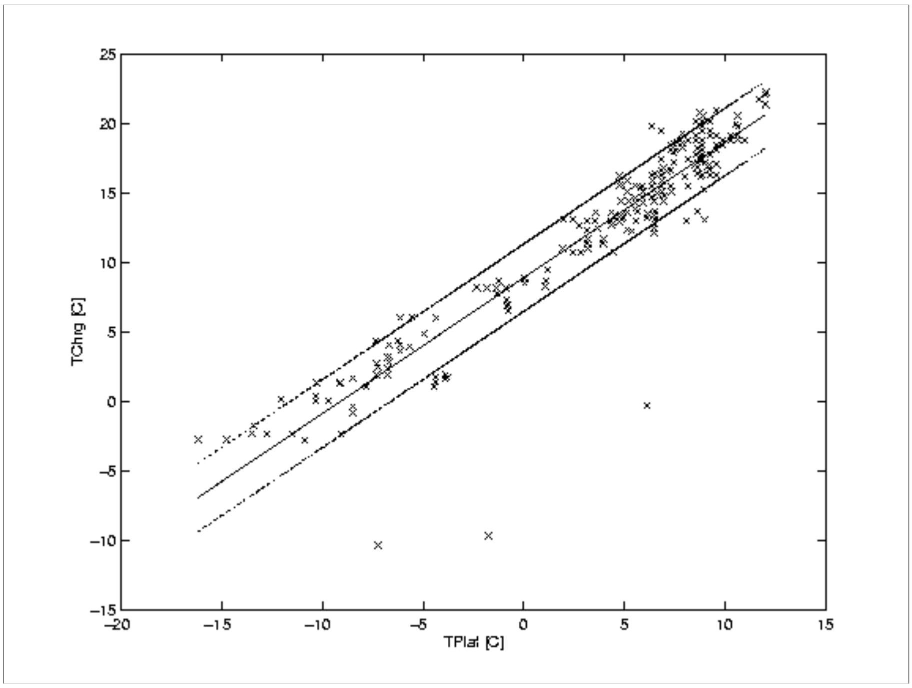

Fig. 6 - TChrg vs. Tplat (Corr = 0.936)

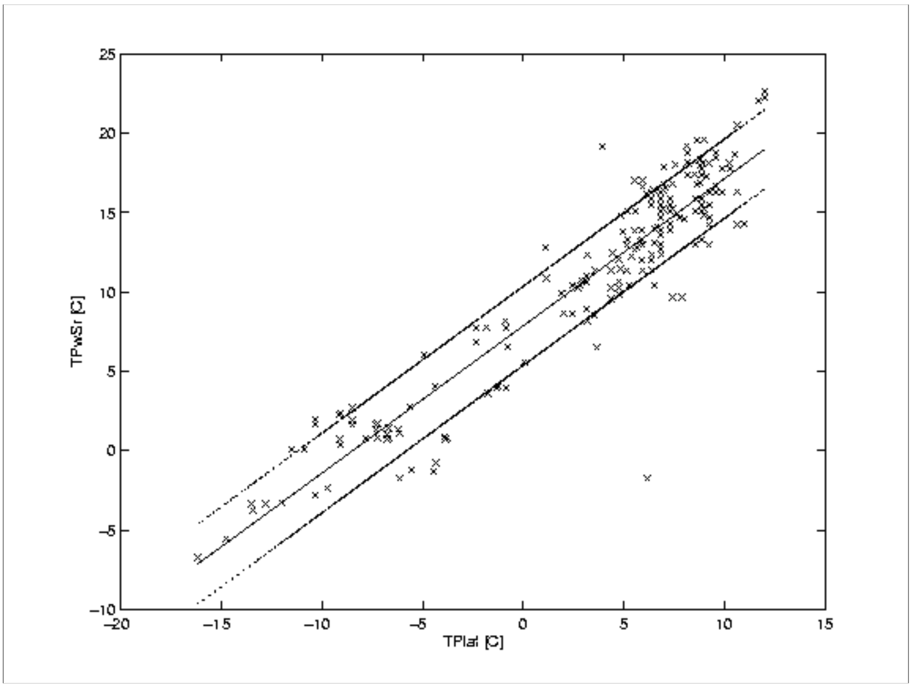

Fig. 7 - TPwsr vs. Tplat (Corr = 0.926)

Figures 6 and 7 show very well-behaved linear regressions, demostrating that internal structure serve as an efficient heat-conducting device.

5. CONCLUSSIONS:

Main conclussions obtained from this analysis concern to evaluation of the capability of the spacecraft structure to transfer heat in an adecuate way; these may be summarized as follow:

- Internal structure shows a good heat transfer capability, assuring temperature equalization between different internal components.
- Solar panels present mild service temperatures, which allows high efficiency of energy generation, as well as long service life (in fact, solar cells have presented no noticeable degradation up to date).
- Internal thermal insulation (multi-foil blankets) showed good efficiency, allowing a good definition of thermal paths.
- Battery load cycle proved to be a complex phenomenae and, when overheating happens, thermal dissipation becomes unsufficient to assure correct service temperature of batteries. A redesign of battery pack, together with active thermal control, involving battery charge cycle, was neccesary; in fact, this has been taken into account in **µSat-2** design.

Concerning to instrumentation, more measurement points, as well as continuous data collection would be highly desirable; these feature has been also implemented in **µSat-2** (Zapico & Torresán, 1998).

Also, solar and earth albedo irradiation measurements would be highly desirable in order to improve thermal control process experimental identification .

Finally, the stochastic process approach used in this analysis showed to be a powerful and efficient tool in order to evaluation and identification of in-flight thermal behaviour of **µSat-1**

6. ACKNOWLEDGMENTS

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