Towing options to the graveyard for the ARABSAT satellites or other 3-axis satellites

Charis S. Kosmas[1]
Kosmas GEORING Services, Darmstadt, Germany, 64283

The issue of re-orbiting 3 axis satellites using external means is investigated. Design data from a specific satellite model (SPACEBUS® of Thales-Alenia Space) is used for concept validation of three re-orbiting scenarios: dispatching to graveyard, relocation, and salvage. First candidate spacecraft for in-orbit demonstration is selected to be ARABSAT 3A. Two different configuration options are investigated as regards the servicing method. Performance assumptions for the 1st refuelable service vehicle called "Utility Agent" are 1828 m/s Δv and for the first refuelable external engine box, the "Kinitron®," 80 m/s Δv. Both vehicles, the Utility Agent and the Kinitron®, are expected to need refueling on an annual basis. All 3 scenarios basically constitute different forms of life extension or life recovery missions. Future generations of the HERMES system for On-Orbit Servicing shall address salvage optimization issue and operational (Δv) envelope expansion.

I. Introduction

THE MoU signed between ARABSAT and GEORING in summer 2007 has opened the way for assessing life extension missions for the ARABSAT 3A and ARABSAT 2B telecommunication satellites.
GEORING, together with Thales-Alenia Space (manufacturer of SPACEBUS®) have initiated work in analyzing the technical feasibility and business viability of relocation services for these two satellites based on the patented HERMES system. Preliminary results are presented here. The HERMES system for On-Orbit Servicing envisages employing two different vehicles for servicing, the "Utility Agent" or UA (a kind of Tug) and the "Kinitron®" (a simple externally mounted engine box). The two configurations have their own reason of existence and solve different operating requirements, as the first one (UA) addresses better the relocation problem and the other (Kinitron®) the station keeping problem.

II. Design drivers and assumptions

The first generation of Utility Agent(s) is designed to be a compromise between autonomy, performance and responsiveness with high emphasis on safety. In order to alleviate concerns of possible collision the mass of the UA is limited to 300 kg and the Z-axis thrust limited to 4 x 10 Nt. Appendages are totally eliminated. This limitation to the total mass imposes limitation to the fuel storage capacity, which is 200 kg of hydrazine. The selection of hydrazine as propellant for the first generation of HERMES spacecraft (UA and Kinitron®) is driven by the requirement to simplify the fuel transfer interfaces and processes.

As a result of the above limitations the Isp is limited to 220 s and the total burn time to 3 hours. Different models of commercial thrusters under consideration have demonstrated lifetimes from about 24 to 50 hours, which means the UA will have, as a lower limit of operational envelope, 8 refueling cycles in total and an upper limit of 16 refueling cycles. The later dictates the design of a tanker spacecraft sized at a minimum of 1600 kg of fuel.

For a given fuel load of 200 kg the total Δv of the UA is 1828 m/s when it would navigate without a load, while when it would carry a satellite of the class of ARABSAT-3A (1250 kg) it shall provide a Δv of 288 m/s.

As regards the Kinitron® it is assumed to carry 50 kg. of fuel. Its performance under three assumptions of dry mass values are as depicted in Table 1. The Kinitron can be employed (mounted on the client satellite (CS)), as a single unit or in pairs. Therefore the Table 1 provides the Δv in the case of a single

Table 1. Δv by single Kinitron® and pair

	K dry mass(kg)			
	25	50	75	100
K+CS	83	81	80	78
K+CS+K	160	154	149	144

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[1] Manager, On-Orbit servicing, 3 Gruener Weg, 64283 Darmstadt, Germany, AIAA Member.

Kinitron® in row one and the sum of Δv of two Kinitrons® in row 2.

The Δv required for a re-orbiting mission to a graveyard orbit 300 km above GEO is 11 m/s. In order to calculate various scenarios of re-orbiting, relocation, salvage missions the Table 2 has been calculated.

III. Mission planning

In order to keep the dry mass of the UA to absolute minimum the mission baseline is to launch the UA directly to GEO. Following GEO injection the UA will have to phase its orbital parameters with ARABSAT 3A.

The Table 2 has the Δv figures required for generic phasing depending on longitudinal distance in steps of 10 degrees and urgency of phasing in steps of days from 1 to 30.

Table 2. Two-burn Δvs for re-phasing by Number of Revs and re-phasing Amount(deg).

Rev	-10	-20	-30	-40	-50	-60	-70	-80	-90	-100	-110	-120	-130	-140	-150	-160	-170	-180
1	55	108	158	205	250	293	334	373	411	447	481	515	546	577	607	635	662	689
2	28	55	82	108	133	158	182	205	228	250	272	293	314	334	354	373	392	411
3	19	37	55	73	91	108	125	141	158	174	189	205	220	235	250	265	279	293
4	14	28	42	55	69	82	95	108	120	133	145	158	170	182	193	205	216	228
5	11	23	34	45	55	66	77	87	98	108	118	128	138	148	158	167	177	186
6	9	19	28	37	46	55	64	73	82	91	99	108	116	125	133	141	149	158
7	8	16	24	32	40	48	55	63	71	78	86	93	100	108	115	122	129	137
8	7	14	21	28	35	42	49	55	62	69	75	82	88	95	101	108	114	120
9	6	13	19	25	31	37	43	49	55	61	67	73	79	85	91	96	102	108
10	6	11	17	23	28	34	39	45	50	55	61	66	71	77	82	87	92	98
11	5	10	15	20	26	31	36	41	46	50	55	60	65	70	75	80	84	89
12	5	9	14	19	23	28	33	37	42	46	51	55	60	64	69	73	78	82
13	4	9	13	17	22	26	30	34	39	43	47	51	55	59	64	68	72	76
14	4	8	12	16	20	24	28	32	36	40	44	48	51	55	59	63	67	71
15	4	8	11	15	19	23	26	30	34	37	41	45	48	52	55	59	63	66
16	4	7	11	14	18	21	25	28	32	35	38	42	45	49	52	55	59	62
17	3	7	10	13	17	20	23	26	30	33	36	39	43	46	49	52	55	59
18	3	6	9	13	16	19	22	25	28	31	34	37	40	43	46	49	52	55
19	3	6	9	12	15	18	21	24	27	30	32	35	38	41	44	47	50	53
20	3	6	8	11	14	17	20	23	25	28	31	34	36	39	42	45	47	50
21	3	5	8	11	13	16	19	21	24	27	29	32	35	37	40	42	45	48
22	3	5	8	10	13	15	18	20	23	26	28	31	33	36	38	41	43	46
23	2	5	7	10	12	15	17	20	22	24	27	29	32	34	36	39	41	44
24	2	5	7	9	12	14	16	19	21	23	26	28	30	33	35	37	40	42
25	2	5	7	9	11	14	16	18	20	23	25	27	29	31	34	36	38	40
26	2	4	7	9	11	13	15	17	20	22	24	26	28	30	32	34	37	39
27	2	4	6	8	10	13	15	17	19	21	23	25	27	29	31	33	35	37
28	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
29	2	4	6	8	10	12	14	16	18	19	21	23	25	27	29	31	33	35
30	2	4	6	8	9	11	13	15	17	19	21	23	24	26	28	30	32	34

IV. Operational scenarios of the Utility Agent

A. Re-orbit to graveyard scenario

With the above performance figures assuming for example that that a candidate spacecraft will be 30 degrees distance away from the Utility Agent in GEO, and that one month advanced notice will be given, a number of successive re-orbiting missions to graveyard can be performed. With fuel consumption figures of 0.656 kg for meeting a client spacecraft (CS) with a month notice, 7.64 kg to push CS to the graveyard and 1.2 kg for returning UA from the graveyard a total of 21 successive missions could be performed in a total of 21 months.

Given the lower limit of the thrusters to sustain 24 h total burn time or 8 refueling cycles of the UA the overall operational envelope in terms of time for a given UA is 21

SEQUENCE OF EVENTS

- Initial conditions :
  - Utility Agent X degrees Longitude distant from the CS.
- Service request submission ;
- Perform Mission analysis ;
  - Trajectory planning, checking against collision risk free trajectory ;
  - Fuel budget calculation
  - Illumination analysis
  - Timeline generation
- Rendezvous & Docking mission
  - Two (or four) burn manoeuvre. GNC by star trackers.
  - Establish RF links with client spacecraft
  - Circumnavigate CS through a safe path a few times, for reproducing antenna radiation patterns
  - Teleoperation based guidance. Approach for docking. Image processing based final docking control mode.
  - Effect changes in control modes in both spacecraft
- Perform re-orbiting
  - Perform 2/4 burn manoeuvre

months * 8 cycles or 14 years. However, during this duration of time some salvage missions are anticipated to take place and therefore the thrusters' lifetime may be radically shortened. The accumulated total burn life demonstrated by advanced thruster models (50 hours) justifies that salvage missions can reasonably be considered, without imposing an unacceptable (in business terms) degradation of the Utility Agent.

B.Relocation scenarios

Assuming the requirement to relocate a number of satellites by 60 degrees within a timeframe of a month, this would require exactly the same Δv as the re-orbiting to graveyard. Therefore assuming successive missions with 1 week intervals for meeting new clients the consumption would be 8.97 kg for such a fast meeting with the client at a 60 degrees longitude distance and an additional 7.64 kg to push the CS to the new operational position. Twelve such missions would be possible before the UA would need a new re-fueling cycle.

C.Salvage scenarios

Several cases of deficiencies in Δv for reaching GEO have been encountered in the past and recently. These events advocate designing mission scenarios for salvaging stranded satellites. This is also advocated by the margins on accumulated burn lives that several high performance thrusters demonstrate (50 hours).

The ratio of consumption when a UA travels alone for a mission with a particular Δv with respect to the case where it carries a CS is 288/1828 or 0.157. This means that a salvage mission in a single step can be considered if the client satellite is missing only 241 m/s Δv. Multiple step missions are possible up to a total fuel mass burnt of 1600 kg, which is the lower threshold of a supplies delivery mission for the UA.

V. Operational scenarios of Kinitron®

A.Configurations

Certain operational considerations rendered the above scenarios of employing a UA insufficient to cover all needs of operators. In particular, the economic viability of the HERMES programme dictates the allocation of the UA only to relatively infrequent, relatively high thrust missions. It is not financially optimal for station keeping. The one-to-one relationship UA-to-CS is considered not viable commercially.

To address the above deficiency of the UA a Kinitron® spacecraft has been designed with two different configurations. One configuration in which the Kinitron® can be mounted at the bracket of the solar panel of the satellite (Fig. 1 and Fig 2), and a second one which can be mounted at the tip of the solar panel (Fig. 3).

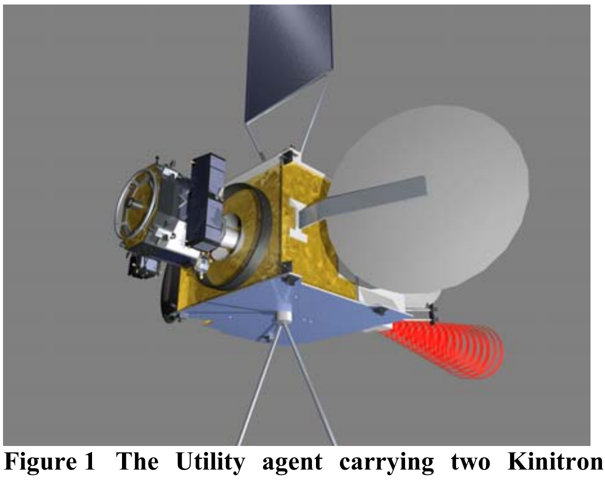

Figure 1 The Utility agent carrying two Kinitrons® while mounted on the ARABSAT 3A spacecraft.

SEQUENCE OF EVENTS

- Service request submission ;
- Perform Mission analysis ;
- Reconfiguration
    - UA equipped with 2 Kinitrons®
- Time line generation – long haul trip
- Rendezvous & Docking mission
    - Docking of UA on Apogee Engine nozzle
    - Activation of delivery mechanism (arm or other.
    - Deployment of Kinitron®-1 and mounting
    - Deployment of Kinitron®-2 and mounting
    - Modification on control modes
- Departure of Kinitron
- Return of Kinitron annually/ biannualy
- Dismounting / Retracking of Kinitron®-1
- Dismounting / Retracking of Kinitron®-2
- Refuelling of Kinitron®-1, 2
- Restoration of Kinitron®-1 in place of Kinitron-2
- Restoration of Kinitron®-2 in place of Kinitron-1
- Departure of UA.

The Fig. 1 shows a simplified mock-up of the ARABSAT 3A. The red cone in front of the satellite represents a prohibited area because it is the field of view (FoV) of the Earth sensor. Nothing shall obstruct this FoV.

The UA can carry with it at any time up to two Kinitrons® mounted according to two different orientations.

Either along the Z axis of the UA or perpendicular. Different control modes are required for these two cases. The delivery of the Kinitrons® for mounting onto the client is a matter of a dedicated study not yet concluded. However several viable alternatives have been identified. Either a dexterous robotic arm or a purpose built segmented beam manifold with a limited number of degrees of freedom.

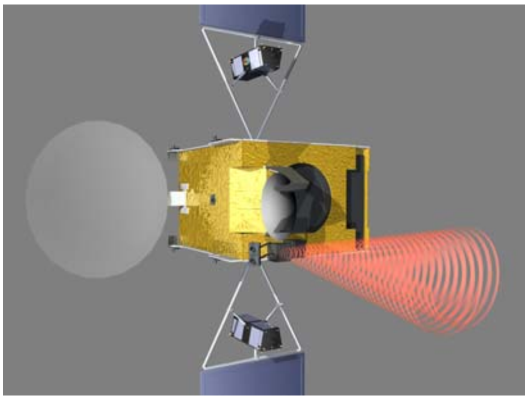

Figure 2. Kinitrons® mounted at brackets of SA.

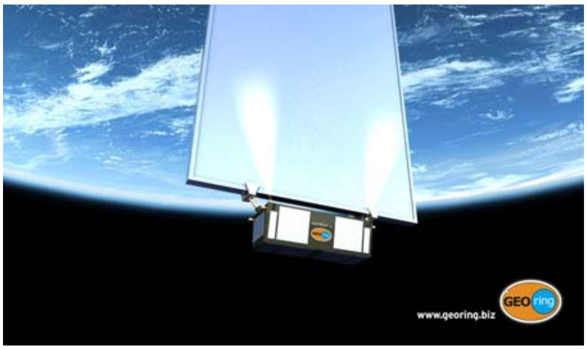

Figure 3. Kinitron® mounted at tip of solar array.

A.Operating parameters

The Kinitron® has been designed to have a fuel capacity of 50 kg which implies 80 m/s Δv to a spacecraft of the class of ARABSAT 3A. If two Kinitrons® would be mounted as in the case of Fig 2. 160 m/s will be available for performing routine station keeping both East-West and North-South corrections.

VI. Conclusion

The analysis so far has not identified a blocking factor for implementing the HERMES system on the basis of UAs and Kinitrons®. Further analysis is needed especially wrt freezing the baseline of propellant selection, mounting, and delivery options of Kinitrons® and of optimizations of UA sizing to respond efficiently to salvage missions.

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