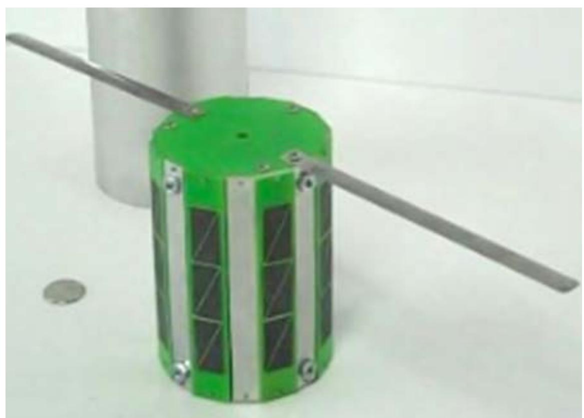
IBM TubeSat Satellite Orbital Debris Report (ODAR)



This report is presented as compliance with NASA-STD-8719.14, Appendix A

Report Version A, 02/15/2016

IBM Research 1101 Kitchawan Road, Yorktown Heights, New York
DAS Software Version Used In Analysis 2.0.2

Record of Revisions				
Rev	**Date**	**Affected Pages**	**Description of Change**	**Author(s)**
A	02/15/2016	All	Initial Release	Theodore van Kessel

Self-assessment and OSMA assessment of the ODAR using the format in Appendix A.2 of NASA-STD-8719.14:
A self assessment is provided below in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14.

Self-assessment and OSMA assessment of the ODAR using the format in Appendix A.2 of NASA-STD-8719.14:

A self assessment is provided below in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14.

Orbital Debris Self-Assessment Report Evaluation: IBM TubeSat Mission

Requirement #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a			x		x			No debris released in LEO. See note 1.
4.3-1.b			x		x			No debris released in LEO. See note 1.
4.3-2			x		x			No debris released in GEO. See note 1.
4.4-1			x					See note 1.
4.4-2			x					See note 1.
4.4-3			x		x			No planned breakups. See note 1.
4.4-4			x		x			No planned breakups. See note 1.
4.5-1			x		x			See note 1.
4.5-2					x			
4.6-1(a)			x		x			See note 1.
4.6-1(b)			x		x			See note 1.
4.6-1(c)			x		x			See note 1.
4.6-2			x		x			See note 1.
4.6-3			x		x			See note 1.
4.6-4			x					See note 1.
4.6-5			x					See note 1.
4.7-1			x					See note 1.
4.8-1					x			No tethers used.

Notes:
1. IBM TubeSat is a secondary payload being launched by the Inter Orbital Systems Company. This ODAR is only for the IBM TubeSat payload and not other portions belonging to other parties.

<u>Assessment Report Format:</u>

ODAR Technical Sections Format Requirements:

This ODAR follows the format set forth by NASA-STD-8719.4, Appendix A.1 and includes all the minimum information for sections 2 through 8 for the IBM TubeSat satellite. Sections 9 through 14 apply to the launch vehicle and will not be covered in the ODAR.

<u>ODAR Section 1: Product Management and Mission Overview:</u>

IBM TubeSat is a mission designed and operated by the IBM T. J. Watson Research Center (IBM Research).

IBM Project Lead : Theodore van Kessel

Project Managers: Theodore van Kessel

Foreign government or space agency participation: None.

Summary of NASA's responsibility under the governing agreement(s): N/A.

Schedule of upcoming milestones:

Launch: October 2016

Mission Overview:

The main goal of the IBM TubeSat mission is to gain experience in the art of operating nano satellites. Our first mission is to launch tube satellites into low earth orbit and establish two way communications.

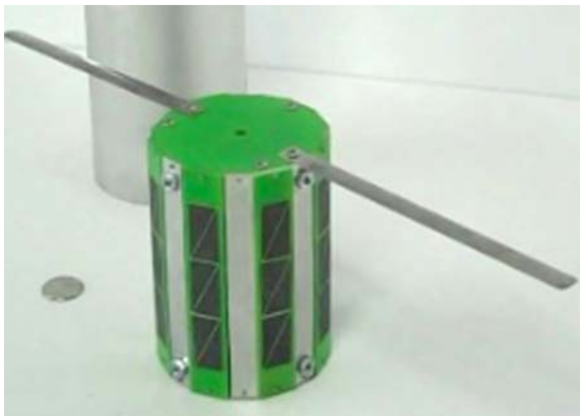
A secondary goal is to operate a simple experimental payload that logs the position of the satellite and transmit the data to our earth station.

The satellites will be launched as a secondary payload oboard a launch vehicle operated by the Interorbital Systems Company. It is expected that the satellite will be injected into a polar orbit from a pacific launch site at an altitude of 310 km at an inclination of 90 degrees.

Transmission will begin immediately post launch in Oct. 2016 and cease from 3 weeks to 2 months after launch (the orbital lifetime of the satellite).

Atmospheric friction will slow the satellite and reduce the altitude of the orbit until de-orbiting occurs 2 months after launch. Please see the Orbital Debris Assessment Report for further details.

The cylindrical dimensions of the satellite are OD = 8.94cm (3.52in), Length = 12.7 cm (5.0 in). The IBM TubeSat will be dispensed from the Interorbital launch vehicle and has no deployables. The total mass will be less than 0.75 kg, and an illustration of the tube sat is provided below.



Launch vehicle and launch site: SpaceX Falcon 9, scheduled for launch from Vandenberg AFB.

Proposed Launch Date: April 2013

Mission Duration: Planned mission operation time of no more than 2 months.

Launch and Deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination:

IOS NEPTUNE modular rocket will launch into an circular orbit with a high inclination. The IBM TubeSats will deploy to and naturally decay from the following orbit:

Apogee: 310 km

Perigee: 310 km

Inclination: 90 degrees

The IBM TubeSat has no active propulsion and therefore does not actively change orbits. There are no parking or transfer orbits.

ODAR Section 2: Spacecraft Description

The IBM TubeSats will fit a 1U tube sat form factor. The cylindrical dimensions of the satellite are OD = 8.94cm (3.52in), Length = 12.7 cm (5.0 in).

The IBM TubeSat main structure includes a cylindrical shell comprised of alternating fiberglass printed circuit board solar panels and strips of aluminum sheet. End caps are formed on the cylinder by circular printed circuit boards.

Total satellite mass at launch, including all propellants and fluids: 0.75 kg.

Dry mass of satellites at launch, excluding solid rocket motor propellants: 0.75 kg.

Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear): None

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes: None

Fluids in Pressurized Batteries: None

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector:

The IBM TubeSat is not planned to have a stabilization system, but may be amended to include a passive magnetic stabilizer

Description of any range safety or other pyrotechnic devices: None.

Description of the electrical generation and storage system: Standard Lithium-Ion battery cells are charged before payload integration and provide electrical energy during the mission until depleted. The cells are recharged by solar arrays, mounted on the satellite body. The charging cycle is managed by the battery cell protection circuit.

Identification of any other sources of stored energy not noted above: None.

Identification of any radioactive materials on board: None.

ODAR Section 3: Assessment of Spacecraft Debris Released during Normal Operations

Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material: None.

Rationale/necessity for release of each object: N/A. **Time of release of each object, relative to launch time:** N/A.

Release velocity of each object with respect to spacecraft: N/A. **Expected orbital parameters (apogee, perigee, and inclination) of each object after release:** N/A.

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO): N/A.

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS v2.0.2)

4.3-1, Mission Related Debris Passing Through LEO: COMPLIANT

4.3-2, Mission Related Debris Passing Near GEO: COMPLIANT

ODAR Section 4: Assessment of Space Intention Breakups and Potential for Explosion

Potential causes of spacecraft breakup during deployment and mission operations:

Given the designed deployment and operations for the IBM TubeSat, there is no normal situation in which the satellite will break up.

Summary of failure modes and effect analysis of all credible failure modes which may lead to an accidental explosion:

In-mission failure of a battery cell protection circuit could lead to a short circuit resulting in overheating and a very remote possibility of battery cell explosion. The battery safety systems discussed in the FMEA (see requirement 4.4-1 below) describe the combined faults that must occur for any of seven (7) independent, mutually exclusive failure modes to lead to explosion.

Detailed plan for any designed spacecraft breakup, uncluding explosions and intentional collisions:

There are no planned breakups.

List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated:

None.

Rationale for all items which are required to be passivated, but cannot be due to their design:

Due to the small size of our satellite, it was not deemed necessary to passivate our batteries.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:

Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon:

For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) (Requirement 56449).

Compliance statement:

Required Probability: 0.001.

Expected probability: 0.000.

>>>>>>>Supporting Rationale and FMEA details:

Battery explosion:

Effect: All failure modes below might result in battery explosion with the possibility of orbital debris generation. However, in the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy, of these small batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the vessel due to the lack of penetration energy.

Probability: Extremely Low. It is believed to be less than 0.01% given that multiple independent (not common mode) faults must occur for each failure mode to cause the ultimate effect (explosion). Additionally, the expected maximum satellite lifetime is less than 2 months - in the unlikely event of debris generation these objects will rapidly reenter.

Failure mode 1: Internal short circuit.

Mitigation 1: Qualification and acceptance shock, vibration, thermal cycling, and vacuum tests followed by maximum system rate-limited charge and discharge to prove that no internal short circuit sensitivity exists.

Combined faults required for realized failure: Environmental testing **AND** functional charge/discharge tests must both be ineffective in discovery of the failure mode.

Failure Mode 2: Internal thermal rise due to high load discharge rate.

Mitigation 2: Cells will be tested in lab for high load discharge rates in a variety of flight like configurations to determine if the feasibility of an out of control thermal rise in the cell. Cells will also be tested in a hot environment to test the upper limit of the cells capability.

Failure Mode 3: Excessive discharge rate or short circuit due to external device failure or terminal contact with conductors not at battery voltage levels (due to abrasion or inadequate proximity separation).

Mitigation 4: This failure mode is negated by a) qualification tested short circuit protection on each external circuit, b) design of battery packs and insulators such that no contact with nearby board traces is possible without being caused by some other mechanical failure, c) obviation of such other mechanical failures by proto-qualification and acceptance environmental tests (shock, vibration, thermal cycling, and thermal-vacuum tests).

Combined faults required for realized failure: An external load must fail/short-circuit **AND** external over-current detection and disconnect function must all occur to enable this failure mode.

Failure Mode 4: Inoperable vents.

Mitigation 5: Battery vents are not inhibited by the battery holder design or the spacecraft.

Combined effects required for realized failure: The manufacturer fails to install proper venting.

Failure Mode 5: Crushing.

Mitigation 6: This mode is negated by spacecraft design. There are no moving parts in the proximity of the batteries.

Combined faults required for realized failure: A catastrophic failure must occur in an external system **AND** the failure must cause a collision sufficient to crush the batteries leading to an internal short circuit **AND** the satellite must be in a naturally sustained orbit at the time the crushing occurs.

Failure Mode 6: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.

Mitigation 7: These modes are negated by a) battery holder/case design made of non-conductive plastic, and b) operation in vacuum such that no moisture can affect insulators.

Combined faults required for realized failure: Abrasion or piercing failure of circuit board coating or wire insulators **AND** dislocation of battery packs **AND** failure of battery terminal insulators **AND** failure to detect such failures in environmental tests must occur to result in this failure mode.

Failure Mode 7: Excess temperatures due to orbital environment and high discharge combined.

Mitigation 8: The spacecraft thermal design will negate this possibility. Thermal rise has been analyzed in combination with space environment temperatures showing that batteries do not exceed normal allowable operating temperatures which are well below temperatures of concern for explosions.

Combined faults required for realized failure: Thermal analysis **AND** thermal design **AND** mission simulations in thermal-vacuum chamber testing **AND** over-current monitoring and control must all fail for this failure mode to occur.

Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about the Earth or the Moon:

Design of all spacecraft and launch vehicle orbital stages shall include the ability to deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or post mission disposal or control to a level which can not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450).

Compliance Statement:

The IBM TubeSat battery charge circuits include overcharge protection and parallel design to limit the risk of battery failure. However, in the unlikely event that a battery cell does rupture, the small size, mass and potential energy of these batteries is such that the spacecraft would be expected to vent gases but any debris from the battery rupture should be contained within the vessel due to the lack of penetration energy.

Requirement 4.4-3. Limiting the long-term risk to other space systems from planned breakups:

Compliance statement:

This requirement is not applicable; there are no planned breakups.

Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups:

Compliance statement:

This requirement is not applicable. There are no planned breakups.

ODAR Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2 (per DAS v2.0.1, and calculation methods provided in NASA-STD-8719.14, section 4.5.4):

Requirement 4.5-1. Limiting debris generated by collisions with large objects when operating in Earth orbit: For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001 (Requirement 56506).

Large Object Impact and Debris Generation Probability: 0.00000; COMPLIANT.

Requirement 4.5-2. Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit: For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable post mission disposal requirements is less than 0.01 (Requirement 56507).

Small Object Impact and Debris Generation Probability: 0.00000; COMPLIANT

Identification of all systems or components required to accomplish any post mission disposal operation, including passivation and maneuvering:

None.

ODAR Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

6.1 Description of spacecraft disposal option selected: The satellite will de-orbit naturally by atmospheric re-entry. There is no propulsion system.

6.2 Plan for any spacecraft maneuvers required to accomplish post mission disposal: None.

6.3 Calculation of area-to-mass ratio after post mission disposal, if the controlled reentry option is not selected:

Spacecraft Mass: 0.75 kg

Cross-sectional Area: .011 m^2 (Calculated by DAS 2.0.1).

Area to mass ratio: .011/.75 = 0.015 m^2/kg

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v 2.0.2 and NASA-STD-8719.14 section):

Requirement 4.6-1. Disposal for space structures passing through LEO: A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods: (Requirement 56557)

a. Atmospheric reentry option:

Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or

Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.

b. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.

c. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission.

Analysis: IBM TubeSat will comply with method 'a'. IBM TubeSat orbit will decay 2 months.

Requirement 4.6-2. Disposal for space structures near GEO.

Analysis: Not applicable.

Requirement 4.6-3. Disposal for space structures between LEO and GEO.

Analysis: Not applicable.

Requirement 4.6-4. Reliability of Postmission Disposal Operations

Analysis: Not applicable. The satellite will reenter passively without post mission disposal operations within allowable timeframe.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

Assessment of spacecraft compliance with Requirement 4.7-1:

Requirement 4.7-1. Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:

a) For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).

Analysis: DAS states that IBM TubeSat is COMPLIANT with this requirement. DAS predicts that IBM TubeSat will have no parts capable of full reentry and be capable of human casualty.

Requirements 4.7-1b, and 4.7-1c below are non-applicable requirements because the IBM Tube Sat does not use controlled reentry.

4.7-1, b) **NOT APPLICABLE.** For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica (Requirement 56627).

4.7-1 c) **NOT APPLICABLE.** For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000) (Requirement 56628).

ODAR Section 8: Assessment for Tether Missions

Not applicable. There are no tethers in the IBM TubeSat mission.

END of ODAR for IBM TubeSat

Appendix A: Acronyms

Arg peri	Argument of Perigee
CDR	Critical Design Review
cm	centimeter
COTS	Commercial Off-The-Shelf (items)
DAS	Debris Assessment Software
EOM	End Of Mission
FRR	Flight Readiness Review
GEO	Geosynchronous Earth Orbit
ITAR	International Traffic In Arms Regulations
kg	kilogram
km	kilometer
LEO	Low Earth Orbit
Li-Ion	Lithium Ion
m^2	Meters squared
ml	milliliter
mm	millimeter
N/A	Not Applicable.
NET	Not Earlier Than
ODAR	Orbital Debris Assessment Report
OSMA	Office of Safety and Mission Assurance
PDR	Preliminary Design Review
PL	Payload
ISIPOD	ISIS CubeSat Deployer
PSIa	Pounds Per Square Inch, absolute
RAAN	Right Ascension of the Ascending Node
SMA	Safety and Mission Assurance
Ti	Titanium
yr	year