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OVERVIEW OF PAST AND CONTEMPORARY CONCEPTS FOR ORBITAL TRANSFER VEHICLES

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Abstract

Fully and partially reusable launchers, as well as small launchers, often suffer from limited mission flexibility due to design-driving constraints. Orbital transfer vehicles (OTVs) can compensate for these limitations by expanding the range of accessible orbits. In response to the growing interest in reusable and small launchers, the number of proposed OTV concepts has also increased. Additional, proposed designs offer in-orbit services such as payload hosting, satellite inspection.

This paper presents a literature-based survey of historical and contemporary concepts of orbital transfer vehicles and proposes a classification scheme. Based on this scheme the collected data is analyzed in an attempt to identify tendencies with respect to certain design choices such as primary mission to be served, operation scheme and propulsion type, amongst others.

The survey shows that most OTVs are designed for Earth-bound missions, often use liquid propulsion for its versatility, and are typically launched as part of ground-based missions – frequently as kick stages.

1. Introduction

Following the successful operationalization of reusable first stages – most prominently demonstrated by SpaceX – other companies are now pursuing similar approaches. The next logical step toward a fully reusable launch system is currently under development with vehicles such as Starship. In Europe, related studies into reusable upper stages are also underway [1].

The introduction of reusable upper stages raises questions about the future of in-space operations and infrastructure, as these stages must return to Earth – optimally from low Earth orbit (LEO). While such stages can theoretically access other orbits, the associated fuel costs and performance penalties make them less competitive than expendable upper stages.

As a result, reusable upper stages are typically optimized for LEO missions, which limits overall mission flexibility. Although expendable kick stages can restore some flexibility, they run counter to the principle of full reusability. In contrast, orbital transfer vehicles (OTVs) that remain in space and perform transfers to higher or inclined orbits could provide a compelling solution.

In addition, small satellite launchers often rely on kick stages as well to cover the so-called “last mile”, that is transporting the payload or multiple payloads from the insertion orbit to the destination orbit(s) with high precision.

Several reusable launcher operators, complemented by operators in the small launcher segment, have already identified OTVs as critical for enabling access to more demanding orbits, such as GTO/GEO, or for deploying satellite constellations with precision.

Additionally, the private sector increasingly proposes in-orbit services such as:

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- Payload recovery or end-of-life management for satellites,
- Payload hosting,
- Re-boosting of satellites or space stations,
- Refueling of orbital assets.

This paper will provide an overview of major past and present projects via a literature research, propose a classification scheme. It also presents an analysis of the collected data in order to identify tendencies within the identified concepts with respect to selected classification categories.

2. Context

In recent years, orbital transfer vehicles (OTVs) have attracted increasing attention across the launch industry, in the United States and other space-faring nations, including Europe. The latter hosts several competitors within the private sector that strive for their own proposition of a small launch system while the European Space Agency ESA pursues its own initiative within the FIRST! approach as much as a "hub and spoke" approach for in-space logistics, [2].

Since a growing number of OTV concepts are being developed – or have been proposed historically – we propose to establish a structured overview and classification of the various vehicle types. Such a classification can help clarify their roles within launch architectures, identify key trends, and support future mission planning considering that size and purpose can vary widely.

3. Classification of orbital transfer vehicles

For this literature survey, we classified OTVs along pre-defined categories. To this end, we first attempted to define what an OTV is and what it is not to discriminate it from other constructs operating in space. For our purposes we defined that

- an OTV is an autonomous space vehicle with the purpose to transport items or humans from one point in space to another or to provide pre-defined functionalities to another object operating in space and
- it accomplishes one or more distinct missions each within a limited time frame.
- It is not part of a space transportation system with the purpose to achieve orbital velocities.

As such, an OTV is not:

- a space station that is a space-based infrastructure providing its core functionality (housing astronauts) either permanently or for at least several months while staying in one specific orbit,
- an upper stage of a launch system and as such an OTV does not allow an otherwise suborbital system to achieve orbital velocities.

This definition of OTV applies hence to kick stages as well although these vehicles often are an integral part to space launch systems as long as these kick stages are not necessary to achieve orbital velocities. It shall be noted that occasionally launch operators highlight their kick stage both as orbital velocity delivery system and orbital transfer vehicle. As such, there is a certain grey zone with respect to the kick stage classifying as an OTV. Nevertheless, for the purpose of this paper, we will count kick stages to OTVs as long as the aforementioned definition applies.

From the identified OTV concepts we have setup nine categories for key characteristics that help differentiating and, in fine, categorizing OTVs. Figure 1 shows the categories as a basis for the latter classification of OTVs. It shall however be mentioned that these categories are not meant to be considered exhaustive.

The individual characteristic categories can be explained as follows:

- Mission: This category is related to the target of one mission. An insertion into an Earth orbit, be it by altitude or inclination change or else performed by an OTV is considered an Earth-bound mission. Lunar-bound missions include transport missions from Earth to the Moon but also missions that are purely performed within the vicinity of the Moon. Interplanetary missions would aim at trajectories going beyond the Earth-Moon system.
- Function: This is the task to be performed by the OTV which is not directly but maybe indirectly linked to the target. These functions could be to change the altitude of the orbit or its inclination, to transport cargo

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between one point to an orbital facility (e.g. space station), retrieving waste from an orbital facility, payload hosting (providing certain functionalities to payloads, e.g. attitude control during staying in an orbit, de-orbiting of satellites having reached their end-of-life state etc.

- Objectives: Some OTV concepts are sent on a mission that only have one specific purpose, e.g. offering last-mile coverage to one payload. Others may be used during one mission to insert several payloads in different orbits or to ferry supply to a space station on the arrival leg and taking back waste during the departure leg.
- Operation scheme: We basically distinguish two different operation schemes. One is ground-based which means that the OTV will be launched by a launch system every time it has to execute a mission, whereas space-based concepts stay, once launched, in space and perform their missions from there. We will count OTVs that operate space-based but occasionally may have ground-based operations to the space-based category. The reason for this is that, contrary to ground-based OTV concepts space-based concepts will have to be designed for quite long residing times irrespective of the fact if they are used in a ground-based mode from time to time.
- Payload class: We use following payload classes to categorize OTV concepts depending on their payload performance. Multiple payloads are summed up and treated as one single payload mass irrespective of the deployment scheme etc.
    - Micro: less than or equal to 100 kg
    - Small: 101 kg to 500 kg
    - Medium: 501 kg to 1000 kg
    - Heavy: 1001 kg to 5000 kg
    - Very heavy: 5001 kg to 10000 kg
    - Super heavy: above 10000 kg

For the data analysis in section 6 we will focus on following classification categories since these data was most often available than not:

- Mission,
- Operation scheme,
- Payload class, and
- Propulsion type.

4. Past concepts, projects and realized vehicles

One of the earliest proposals for an orbital transfer vehicle was innately related to the Space Shuttle program, as were many of the concepts of the following two decades. This OTV concept simply named “Space Tug” was developed in the early 70’s, see [3] and meant to expand the launch capabilities of the Space Shuttle to geosynchronous orbits. It was designed to be operated in a ground-based mode and meant to be reusable with a total life time of 20 missions. The Space Tug was designed to stay six days in orbit minimum and to have a total payload of at least 3000 pounds (1360.8 kg) for a transfer from a 100 nautical mile (185.2 km) orbit at inclination of 28.5° to a geosynchronous orbit. Its propulsion system was to be based on LOX/LH2.

The 80’s and 90’s were marked by many further OTV studies that were to expand Space Shuttle capabilities or those of other US-based launch systems. The Payload Assist Modul or (PAM) was among these concepts. While the PAM A, developed by McDonnell-Douglas ([4], [5]) did not go beyond concept phase, its successor PAM-DII ([4], [5]) was operational between 1980 and 1985 whereas PAM-D ([5], [6]) was retired as late as 2009. All PAM models were propelled by a solid propulsion system and as such not destined to be reusable but ground-based. The PAM-A concept was planned to be capable to lift a 2000 kg payload, the payload capability of the PAM-D was about 1260 kg and up to 1880 kg for the PAM-DII, [7]. Figure 2 shows the PAM-D leaving the Space Shuttle payload bay while carrying the SBS-3 satellite.

The Inertial Upper Stage (IUS) was developed by Boeing and its primary use was to serve interplanetary or other institutional missions such as TDRSS satellite delivery, [4]. Noteworthy missions were the launch of the Magellan probe to Venus, the Galileo mission to Jupiter and Ulysses to the polar region of the Sun using a PAM-S (S for special) as a kick motor or the Chandra X-ray Observatory. It was finally retired from operations in 2004 and was principally

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capable to deliver a 2270 kg payload to GEO. As the PAM models, it was propelled by a solid motor. It was ground-based and used on the Titan-4 rocket and the Space Shuttle, [9].

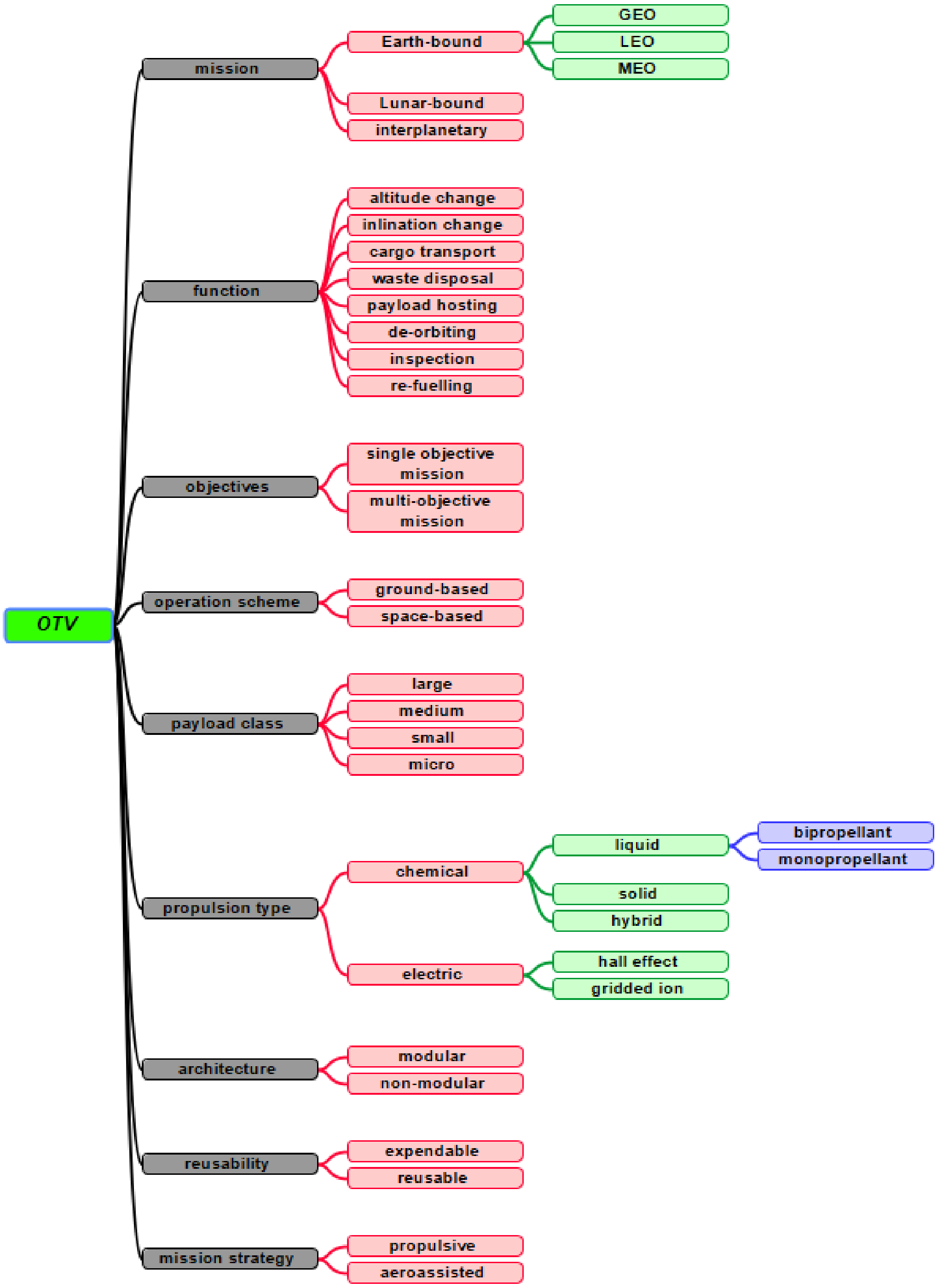

Figure 1: Characteristic categories for OTV classification

Another realized OTV concept was the Transfer Orbit Stage (TOS) resulting from a cooperation between Martin-Marietta Corporation and the Orbital Science Corporation, [4], [10]. It performed its first flight on 25 September 1992 atop a Titan-4 rocket to launch the Mars Observer Probe and was only used another time almost a year later on 12 September 1993 on the Space Shuttle to deliver the Advanced Communication Test Satellite (ACTS), [11]. According to [10], it was planned to have a payload capability of 6097 kg, but if it did have this performance capability, it never came close to use it during its two flights. As the other OTV mentioned above, it relied on a solid propulsion system and was operated exclusively in a ground-based mode.

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Aerojet Technical Systems Company collaborated with Ford Aerospace to develop the concept for the High Performance Propulsion Module (HPPM), [4], for the Space Shuttle and "(…) sized to roughly twice the PAM-D performance" (p. 135, [4]). It was to be propelled by the N_2O_4/MMH TRANSTAR 1 engine.

Figure 2: PAM-D with SBS-3 satellite being deployed from Space Shuttle Columbia during STS-5 mission, [8]

The Aerojet Technical Systems Company developed a further concept for a Space Shuttle upper stage named Liquid Propulsion Module (LPM), [4], with a GEO performance of 1540 kg using the same engine as the HPPM.

Neither the Centaur-G nor the Centaur-G Prime (see [4]) ever reached operational status as a liquid-propelled powerful upper stage or OTV for the Space Shuttle. It was a derivate of the high-performance cryogenic upper stage Centaur in its various subvariants that flew atop of different versions of the Atlas and Titan launch system. The Centaur-G and G Prime were to be propelled by two LOX/LH2 RL10-3-3A engines and meant to provide GEO respectively interplanetary capabilities to the Space Shuttle.

The Apogee and Maneuver Stage (AMS), [4], was planned as an upper stage for the Space Shuttle, and could optionally be used in conjunction with the TOS. It was a concept developed by Orbital Science Corporation and have a payload capability to GEO of 2548 kg, [10], but was never realized.

NASA's Orbital Maneuvering Vehicle, [6], [12], did not go past project phase either. Its function went far beyond the habitual capability enhancements for the Space Shuttle. Apart from payload delivery or multiple payload insertion or transfer to GEO, it was meant to perform servicing tasks such as re-boosting or de-orbiting of satellites, or providing services to large observatories or unmanned platforms launched from the ISS including their retrieval for maintenance purposes. According to Gunn, [6], it was designed to be used "(…) as a reusable remotely controlled, free flying space tug" (p. 327f).

Further concepts for Space Shuttle upper stages that never were built was the Shuttle Compatible Orbit Transfer Vehicle (SCOTS) by RCA Astronautics, IRIS by Aeritalia, both with solid propulsion, and the Satellite Transfer Vehicle (STV) by Scott Science and Technology/British Aerospace (bi-propellant), [4].

In 1980, the preliminary design of a NASA concept of a space-based OTV was presented in [13]. It was designed to ferry payloads up to 50 metric tons from LEO to GEO and was planned to be propelled by four cryogenic 89 kN engines or more for higher payloads. In addition, it should have had a lifetime of 50 missions before being refurbished. Its gross lift-off mass was to be 182 metric tons. This mass is even above the maximum payload mass ever transported into LEO orbit to this date requiring a multi-mission assembly/fueling up. According to the authors [13], "(…) the major design loads are drastically reduced" (p. 256) for a space-based design since the loads experienced during orbital operations are less than during launch. This impacts a ground-based OTV more negatively as it will be launched fully loaded (note by the authors of this paper: contrary to a space-based OTV that would be launched empty and being fueled up when in orbit).

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Apart from the IRIS concept, European companies provided their visions for orbital transfer vehicles. MBB and Aerospatiale proposed the Orbit Transfer and Servicing Vehicle (OTSV), [14], offering transportation, servicing and repair functionalities for then envisaged European COLUMBUS Platform (PF) or the COLUMBUS Free Flying Pressurized Module (FFPM). According to [14], the OTSV should operate between the COLUMBUS-PF or -FFPM and an American crewed space station, the US-MSS (MSS for "Manned Space Station", see [14]). Three scenarios were envisaged with respect to the individual orbits of the COLUMBUS-PF/FFPM and the US-MSS, that involved a coplanar orbit but different altitudes, identical orbit but different true anomaly at a given time or a different inclination. Envisaged transport tasks included the transport of crew members between both space assets and a recovery of the OTSV by the Space Shuttle or the HERMES vehicle for some of the scenarios. Ariane 5 or the Space Shuttle would place the OTSV into its orbit.

Another European proposal, the Automatic Servicer, was presented by the French space agency CNES, [15]. This orbital transfer vehicle was to perform in-orbit inspections, visual assistance for satellite deployment and handling operations for telecommunication satellites. It would carry containers with spare modules in a weight range of 50 to 200 kg. Its propulsion was planned to be based on LOX/LH2 and should operate in GEO.

In [16], Matra Espace presented the Teleoperated Service Vehicle (TSV) that should be capable to place spacecraft in their orbits, retrieve and to provide servicing to spacecrafts and offer logistic support for space stations. Several mission scenarios were envisaged, involving space-based transfers between a spacecraft and a space station, from a launch vehicle to a space station. Another mission scenario was a ground-based transfer to an orbit with a launch by Ariane or the Space Shuttle and a recovery by the Space Shuttle.

The Automated Transfer Vehicle (ATV), [17], was a major European contribution to the International Space Station (Figure 3). Its primary task was to supply the ISS and dispose of waste produced by and onboard the ISS. It was launched five times atop the Ariane 5 rocket, with a payload up to 7700 kg. It performed one round trip before being disposed upon atmospheric re-entry. Its last flight was on 29 July 2014.

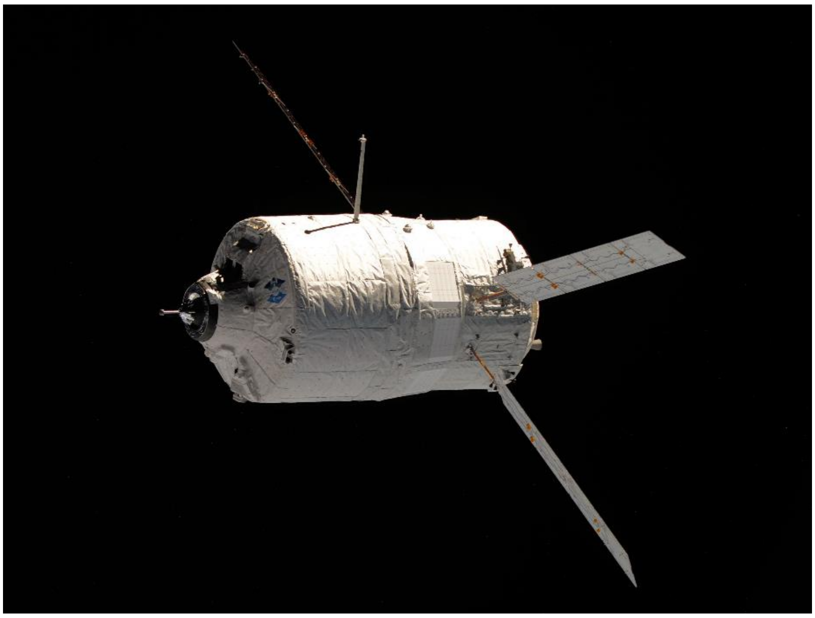

Figure 3: Automated Transfer Vehicle, [18]

The UK-based Orbital Recovery Limited presented in [19] the development state of the Orbital Life Extension Vehicle (OLEV) concept. This space tug concept was to mate with existing spacecraft in GEO or intended for GEO orbits in order to provide station keeping and attitude control functionalities to these spacecrafts. In that manner satellites that would have reached their end-of-life after 10 or 15 years when all onboard fuel was depleted could continue to operate. It was to be launched by Ariane 5 and would be propelled by a Hall Effect Thruster and enough fuel to maintain station keeping and attitude control services for a 3000 kg GEO satellite for another 10 years.

5. Present landscape of OTVs

In the wake of the emerging landscape of new small launchers and the push for reusable launch systems, new OTV concepts are proposed. This section attempts to give an overview of contemporary concepts that may still be under development or which already performed flights. A considerable rise in OTV (and Orbital Maneuvering Vehicles

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OMV) is observed after 2020, cumulating for now in a launch of 18 commercial vehicles in 2023, see [20] (Figure 10.8, p. 291). Considering the very dynamic and sometimes volatile environment of startups proposing complementary services as the bigger companies well established since a long time this overview does not pretend to be exhaustive let alone complete.

Many of these concepts fall into the category “kick stage” enlarging the mission spectrum for the actual launch system. ArianeGroup, the developer of the Ariane 6 launch vehicle is currently developing the ASTRIS kick stage, [21]. It is planned to perform spacecraft delivery from GTO to GEO, on trajectories for exploration missions and multi-orbit delivery for constellations. For the latter, it is capable to carry a total of up to 4500 kg in payload mass.

In the United States, established launch developer like SpaceX or Blue Origin, propose each their own solution for an OTV. The now decommissioned Dragon capsule from SpaceX, [22], supplied the International Space Station, while its successor Dragon 2, [23], can also transport crew members to and from the ISS. This capsule had its first test flight in 2019 (un-crewed Demo-1, crewed test flight Demo-2 in 2020, [22]) and can carry 3307 kg to the ISS and retrieve 2507 kg from it. Dragon 2 nominally transports four crew members but is capable to provide emergency return capacities for the seven crew members aboard the ISS. It is propelled by 16 hypergolic Draco thrusters whereas their launch escape system is propelled by eight SuperDraco engines running on hypergolic liquid propellant as well.

Blue Ring is a versatile OTV concept by BlueOrigin, [24], that is a versatile spacecraft intent to perform in space logistic tasks and delivery, such as refueling, serve as data relay etc. Its first flight was on January 16, 2025, according to the company announcement [25].

In 2013, Orbital Science Corporation has put the Cygnus capsule into operations that performs supply and orbit lifting tasks to the benefit of the ISS, [26]. It can be flown atop of either the Antares, the Atlas V or the Falcon 9 rocket.

Apart from these big names in the current launcher market, startups and new launch providers have their own propositions for orbital transfer vehicles, including kick stages. Given the number of initiatives to develop new launchers, mostly in the small and medium size segment, it is probably impossible to be exhaustive. As such we propose to focus on more prominent initiatives where enough information is available.

Firefly Aerospace, who successfully developed its Alpha rocket (payload class of about 1 metric ton into LEO), currently develops three variants for their Elytra OTV, [27]:

- Elytra Dawn: target orbit LEO, single mission, payload stacks up to 1000 kg,
- Elytra Dark: target orbits cis-lunar and beyond, persistent in orbit, payload stacks up to 16 metric tons, and
- Elytra Dusk: transfer from LEO to GEO, payload stacks up to 16 metric tons.

Rocket Factory Augsburg (RFA) proposes the Redshift OTV for their RFA One launcher. According to company information [28], this OTV shall be used to position orbital spacecraft or other in-orbit services like altitude, phase or inclination changes. They announce further functionalities like payload hosting, satellite inspection, space debris removal, end of life management or life extension services. It shall have a modular architecture and serve a wide range of orbits, including SSO, MEO, GTO, GEO and Lunar Transfer Orbits (LTO) with a payload capability ranging from 150 kg into GEO to 1300 kg into a 500 km SSO.

Rocket Lab has flown its Photon spacecraft, [29]. It is used to deliver payloads to their respective orbit once launched. According to [30], it has a launch mass of 50 kg and has been launched successfully several times since its first flight in August 2020, three times atop the company’s own launcher Electron, once atop a Falcon 9.

Some companies offer orbital transfer or servicing vehicles as a stand-alone product. One example is Exotrail (see Figure 4) that has already put its SpaceVan, [31], into operations with a first satellite release on March 6, 2024, [32]. They propose last mile delivery (e.g. from GTO to GEO), payload hosting and plan to provide payload inspection services as well. It can be fitted to a Falcon 9, [33], but is also planned to be launched atop an Ariane 6 rocket, [34].

Northrop-Grumman’s Mission Extension Vehicle 1 (MEV-1), [36], was launched successfully in 2019 as a space-based OTV successfully repositioning Intelsat-901 on its geosynchronous orbit, being a world’s first in autonomously docking with a spacecraft. In April 2025, MEV-1 detached from the satellite after having placed it in a graveyard orbit. The succeeding MEV-2 was launched in August 2020 by an Ariane 5 docking with Intelsat 10-02 on April12, 2021.

Momentus Space offers “(…) in-space infrastructure services (…)”, [37], such as transporting satellites and providing payload hosting services. Its Vigoride performed its first demonstration flight in May 2022 and its first commercial mission in April 2023, [38]. According to [38], Vigoride has a payload capability of 750 kg into LEO.

D-Orbit launched its ION Satellite Carrier, [39], on top of a Falcon 9 in December 2023. It provides deployment and hosting services for CubeSats up to a mass of 160 kg according to the company.

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Mira is an OTV proposed by Impulse Space, [40]. It performed its first flight in November 2023 releasing a CubeSat in a LEO orbit, [41]. It shall serve orbits ranging from LEO, MEO, GEO, to Cislunar and beyond, offering a payload capability up to 300 kg at a Delta-V of 500 m/s. It has a bi-propellant propulsion system running on Nitrous oxide and ethane. According to [42], Mira has a weight of 300 kg itself.

UARX Space proposes OSSIE which stands for Orbit Solutions to Simplify Injection and Exploration, [43]. It is advertised as a facilitator for CubeSats for achieving their final orbit and to provide inclination and altitude change possibilities. In addition, it shall assist in phasing tasks for constellations. Its propulsion runs on Nitrous Oxide/Propylene and it offers a 200 kg payload performance for a 240 m/s velocity increment.

Figure 4: Exotrail’s SpaceVan, artist’s impression, [35]

UARX has as well initiated development work on LUCAS or Lunar Cargo Service which shall provide cargo services to the Moon with a payload capability up to one metric ton, [44]. According to the UARX website dedicated to LUCAS, the development work has completed phase 0 status.

To complete this section (without pronouncing being complete) we want to mention that workhorse for ISS supply in the shape of the Progress spacecraft, that has delivered goods to various space stations since the late 70’s, alongside its crewed version Soyuz, [45]. Progress has a payload capability of roughly 2200 to 2600 kg depending on the variant. It has a 30 day in-space autonomy capability and is, in addition to resupplying the space station, the task to re-boost the ISS.

The Chinese Tianzhou, [46], assumes the corresponding tasks to the Chinese Tiangong space station as does the Progress spacecraft. It was first launched in 2017 on Long March 7 and offers about 7400 kg cargo capability in its improved version.

6. Analysis of data with respect to the proposed classification scheme

Unfortunately, most data sets tend to be rather incomplete with respect to the classification categories rendering the classification difficult. What we can say is that the vast majority of the concepts, whether realized or not, are focused on Earth-bound applications. Thirty-three out of fifty-one concepts either are dedicated to Earth-bound missions only, or to services to a space station or offer a mix of missions including Earth-bound ones. If we concentrate on those spacecrafts that shall serve exclusively Earth-bound applications we still identified twenty vehicles, that is 39%, see Figure 5. Another important segment is linked to the servicing of space stations amounting to 12% of all identified OTVs. Spacecraft intended for a more flexible mission portfolio are slightly more numerous representing 14% of the investigated sample.

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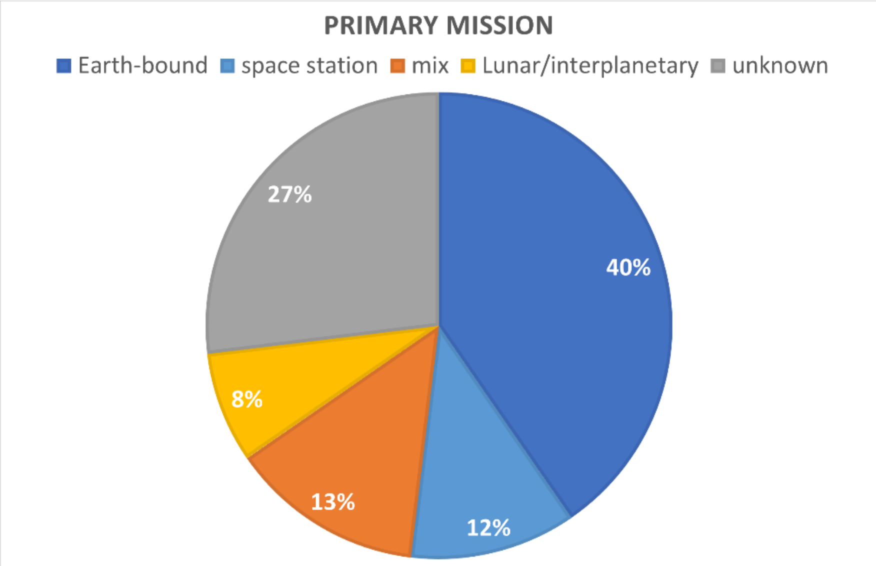

Figure 5: Primary missions of OTVs

Focusing on OTVs with a primary Earth-bound mission or a mix of missions, the overwhelming majority of those giving details of their specific target operational orbits offer missions in or to GTO and/or GEO. Only seven percent of all OTVs with Earth-bound missions do not offer GTO or GEO services, see Figure 6. This tendency reflects the fact that may launch systems for which OTV and kick stages are designed need these vehicles to access such high energy orbits.

It shall be mentioned that vehicles targeting specifically space station services as their primary mission like Progress or Cygnus were excluded from this consideration as none are known to the authors of this study offering such high energy missions.

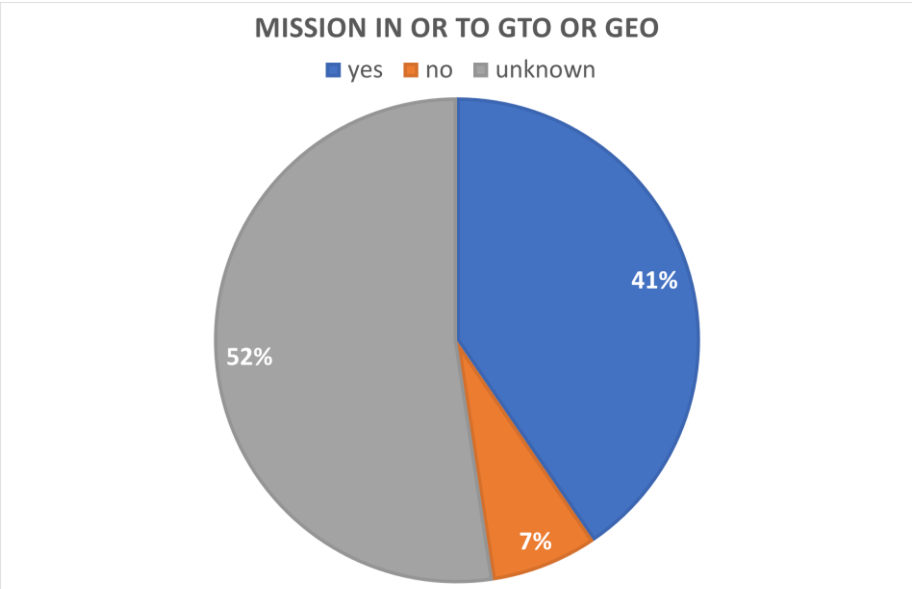

Figure 6: Portion of Earth-bound OTV targeting GTO/GEO

As shown in Figure 7, more than 50% of all OTVs are ground-based that is they are launched into orbit by a launch system each time whereas space-based OTVs meant to stay and operate from space sum up to only one out of ten. Only a small fraction of the investigated OTVs may be either operated from ground or space.

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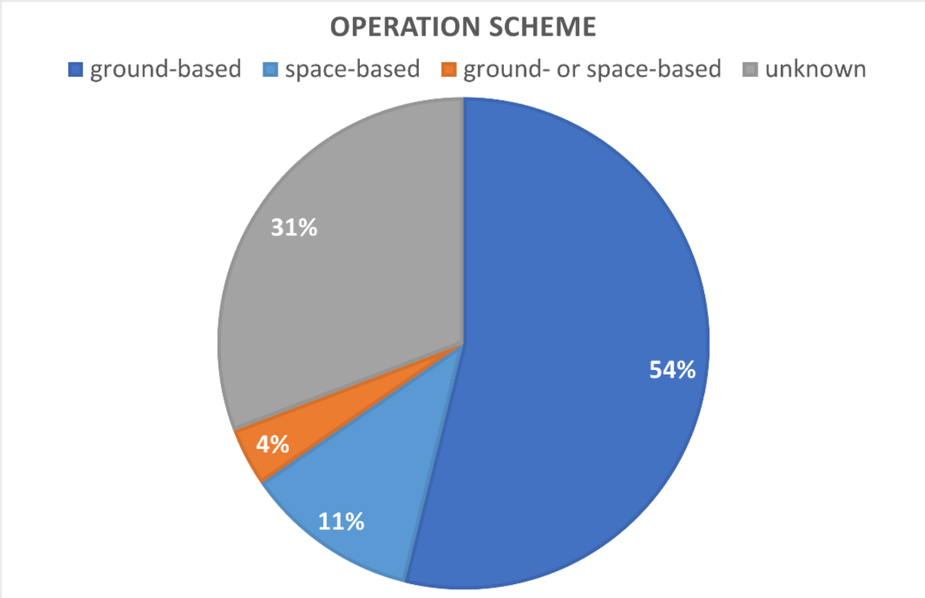

Figure 7: Operation schemes

Figure 8 shows the distribution of propulsion types among the investigated orbital transfer vehicles. More than one out of four orbital vehicles sport a liquid propulsion system which is not surprising considering that liquid propulsion offers higher mission flexibilities due to its re-ignition capabilities compared to solid propulsion and higher thrust and hence shorter mission times compared to electric propulsion. Yet, at least 10% rely on solid propulsion. Concerning the OTV with propulsion system labelled "bi-propellant, these could be liquid propulsion as well but since we could not exclude entirely that some of them are using hybrid propulsion we decided to use this as a separate category.

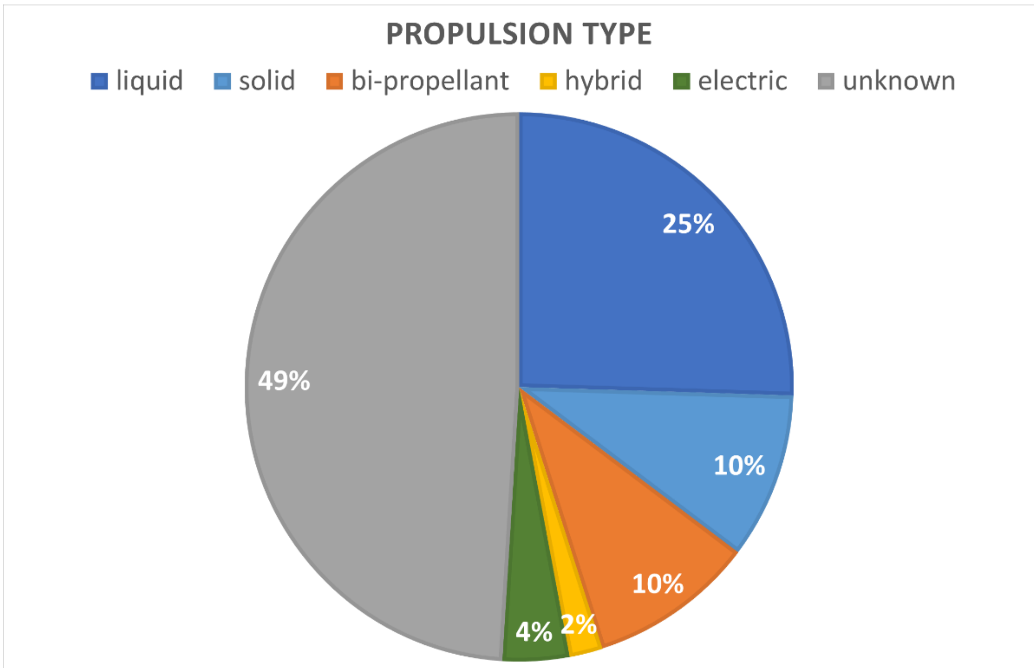

Figure 8: Propulsion Type

As for the payload class, the by far largest category is that labelled "heavy" that covers a payload mass ranging from 1000 kg to 5000 kg followed by the "small" (100-500 kg) and "very heavy" (5000-10000 kg), see Figure 9.

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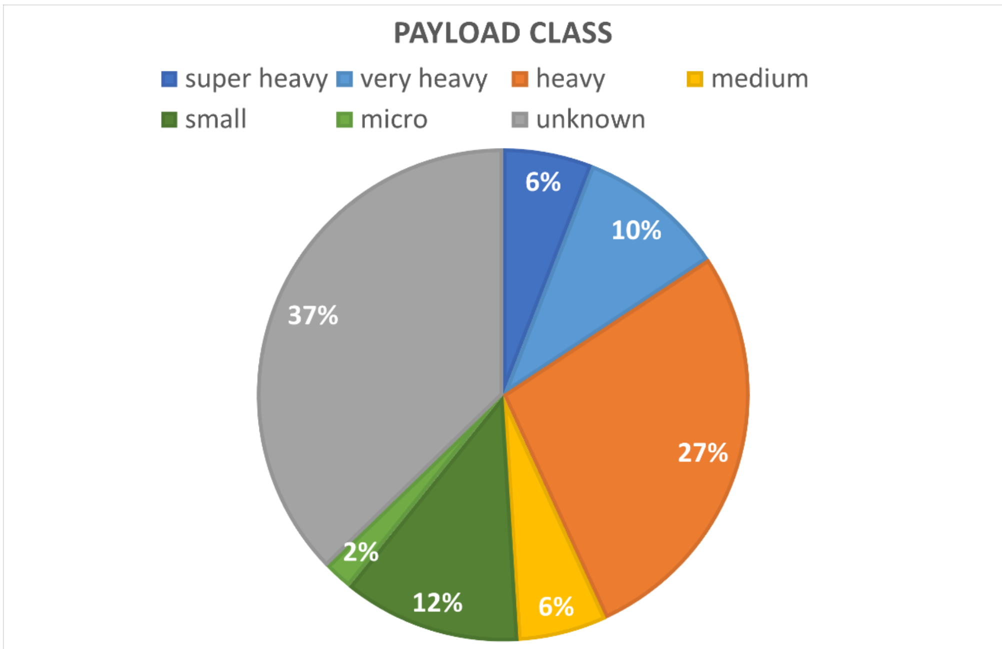

Figure 9: Payload class

7. Summary

Past development activities for orbital transfer vehicles (OTVs) were closely linked to the Space Shuttle program, which—due to inherent design constraints—lacked the capability to deliver payloads to high-energy orbits.

In recent years, the rise of reusable and small launch vehicles has renewed interest in the development of OTVs, as these systems are increasingly seen as a means to extend mission capabilities beyond the limitations of the launch vehicles themselves.

To identify recurring trends and design preferences, a survey of historical and current OTV developments was conducted. As a basis for this analysis, a classification tree was developed, enabling a structured assessment of the various systems.

The analysis focused on the following classification categories:

- Primary mission type (e.g., Earth-bound, interplanetary)
- Operation scheme (ground-based, space-based, or hybrid)
- Propulsion type (liquid, solid, electric, hybrid, etc.)
- Payload class

The results show that the majority of OTV concepts are intended for Earth-bound missions. When including missions targeting the ISS or other space stations, more than half of the investigated concepts fall into this category.

Ground-based operation schemes clearly dominate. This can largely be attributed to the inclusion of kick stage-type systems in the analysis, which are, by definition, launched from Earth and operate in a single-use configuration.

As expected, liquid propulsion is the most commonly used system type, owing to its high performance and operational flexibility.

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