International Journal of Aviation, Aeronautics, and Aerospace

Volume 9 | Issue 1 Article 2

2022

SPACE CARGO: Ultra-fast Delivery on Earth –Potential of Using Suborbital Space Vehicles for the Transportation of Cargo

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Cover Page Footnote

This conceptual paper sheds light on the feasibility of technical and economic scenarios, and ecological justifiability of dedicated cargo transportation using suborbital and orbital vehicles. The concept of space cargo is a mixture of the two disciplines: traditional transportation of cargo, in particular air cargo, and commercial suborbital flights, in particular space tourism. This paper qualitatively analyzes space cargo scenarios from different viewpoints and gives recommendations for each typical characteristic cargo group. The finding of this paper indicates that there may be limited demand for the movement of cargo by rockets, as the economically feasibility will be limited in the short to mid-term (0–50 years).

The idea of suborbital space cargo transportation has been around since at least the 1960s when Bentivoglio (1969) published a paper on the *Juridical problems of sub-orbital space transport: Legal aspects of suborbital space transport based on air transportation concepts* and Cremona (1969) presented a paper titled *Suborbital space transports problem solution by recoverable jet orbital or jet assisted aircraft, discussing implications of Concorde supersonic flight*. However, since then the literature has been quiet about the use of suborbital or orbital vehicles to transport cargo from one point on the Earth's surface to another. Instead, the literature has mainly focused on cargo transportation to orbiting space stations, and more recently to other celestial bodies.

The movement of cargo by air has been around since 1910 when 200 pounds (91 kg) of silk was carried 65 miles (105 km) from Dayton to Columbus, Ohio (Allaz, 2004). In 2019, there were 215,169 million ton-km of freight moved by air, and this number is expected to grow by about 3% per year (Air Cargo World, 2016; The World Bank, 2021). Air cargo is critical to the world's economy and has the advantages of fast, worldwide delivery of goods and is typically used to transport high value, perishable, or time sensitive goods.

Unmanned commercial suborbital flights are currently being used for weather forecasting, observation, and microgravity experiments. Typically, unmanned research missions are used to test the system before using the rocket for manned flights (Foust, 2017). Suborbital spaceflight is when a space vehicle reaches at least 100 km (62 miles) above sea level (the Kármán line) and then returns to Earth without completing a full orbit of the Earth (Santoro et al., 2014). Suborbital space vehicles are not designed to reach sufficient velocity to enter Earth orbit. On the other hand, orbital space vehicles are able to reach and maintain an orbit around the Earth. In recent years, several organizations (e.g., Virgin Galactic, Blue Origin, and SpaceX) have visions or are close to being able to provide *regular* space transport for *commercial* space tourism. However, commercial space flight for tourism and re-supply of orbiting space stations is just in its pioneer phase: only seven space tourists visited the International Space Station (ISS) between 2001 and 2009 (Space Adventures, 2013) and starting in 2008, NASA awarded two contracts to SpaceX and Orbital ATK for cargo re-supply to the ISS (NASA, 2017). In 2021, Virgin Galactic, Blue Origin, and SpaceX completed the first, but still *non regular*, commercial space flights to carry passengers on a flight. With the development of reliable space vehicles, the possibility of transporting cargo via suborbital flight should be considered.

This paper outlines current suborbital and orbital space vehicle development and expected capabilities, and explores the idea of suborbital and orbital vehicles to transport cargo between two points on the Earth's surface. The assumptions made in this paper are based on current thoughts of the development of space travel in the future. The authors have assumed that the development of space travel will accelerate in the future and have based the assumptions made in this paper on the existence of reliable, safe, and fully developed space transportation systems. The actual timeline for when a fully developed space transportation system will be in place is unknown at this time, but it is reasonable to assume that this will occur within the next 25 years. The research question (RQ) to be explored using a qualitative essay format is: *To what degree does the transportation of cargo by space vehicle make sense?*

In the next section, we provide some background on the transportation of cargo by aircraft and space flights. Section three covers expected operation, cargo, and flight path possibilities. Section four, the methodical base of this study, focuses on evaluating the various scenarios driven by the operation type. Section five implications and recommendations outlines four scenarios. Finally, section six provides our concluding remarks.

Background

Air cargo transport is the movement of goods by aircraft. About half of all air cargo is moved in the cargo hold (belly) of passenger airlines with the rest being moved on dedicated freighter aircraft. The fast transportation of goods is important for just-in-time production operations and for the transport of perishable and high value goods (ACI-NA, 2019). The transportation of goods by air has the benefit of speed, reliability, and security (ACI-NA, 2019). For cargo movements of less than 800 miles (1,287 km), one of the other modes of transportation (road or rail) is normally considered a better option, but for cargo movement over 800 miles air comes into consideration (Novack et al., 2018).

Table 1 provides a list of the type of goods typically transported by the five traditional modes of transportation. For this study, the type of goods carried by *airline* would be the type that would be considered for suborbital space transportation.

Table 1
Typical Types of Cargo Carried by Mode

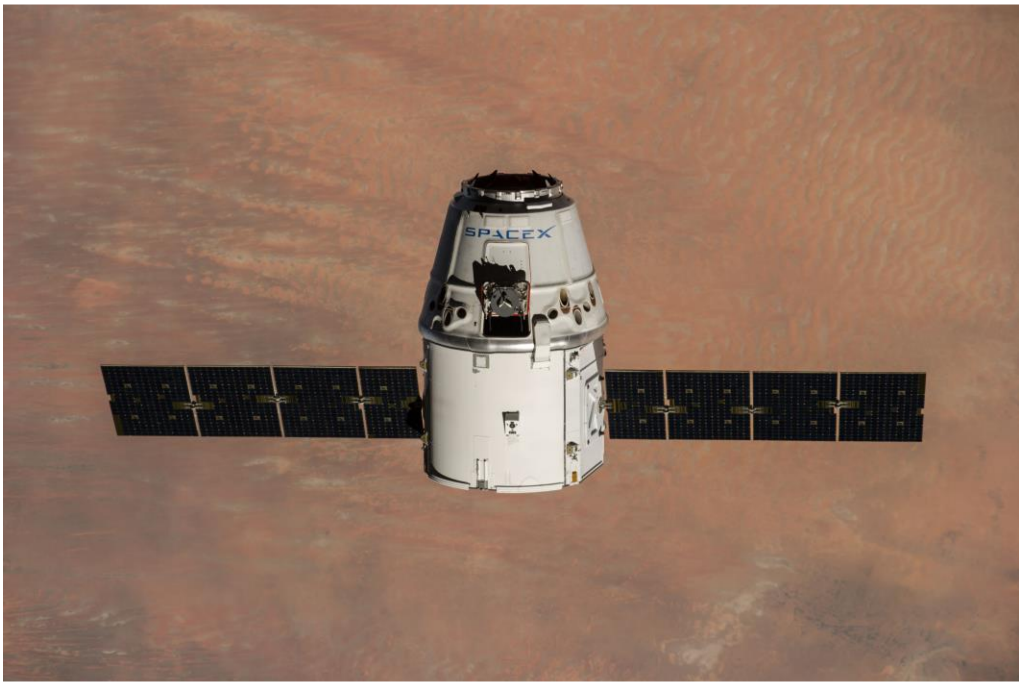
Mode of Transport	Common Type of Cargo Carried
Motor carrier	Smaller shipments: food and manufactured products, consumer goods, livestock
Railroad	Low-value commodities: coal, chemical, farm and food products, motor vehicles, nonmetallic minerals
Airline	Emergency and high value shipments: mail, fresh flowers, race horses, jewelry, critical parts
Water carrier	Bulk goods: chemicals, coal, petroleum, food and farm, crude materials
Pipeline	Bulk liquids: oil, natural gas, coal (in slurry), chemicals

Note. Modified from Novack et al., 2018.

A literature search revealed several papers on the transportation of cargo via space flight (e.g., Anderson, 2013; Chapman, 2020; Government Accountability Office, 2011; Lambright, 2015; Lin et al., 2014); however, these studies typically outlined the requirements and needs for suppling orbiting space stations (Figure 1), i.e., the ISS, and not for the commercial transportation of goods to two points on the Earth's surface. With the closure of the U.S. Space Shuttle program, there has been a growth in commercial cargo market to supply the ISS. In theory, the commercially developed vehicles with a reentry capsule could be used to transport cargo terrestrially, while other vehicles in use typically burn up during reentry in the atmosphere.

Figure 1

SpaceX Dragon Commercial Cargo Spacecraft Approaches the ISS in 2014.



Note. Source NASA. In the public domain.

Currently, the spaceflight industry is very capital intensive and requires highly skilled human resources with no guarantee of success (Giacalone, 2013). According to Giacalone (2013), profitability for any type of commercial space projects in the short term (3–5 years) is highly unlikely. However, with the recent success of SpaceX suppling the ISS, profitability should not be too far off. These programs and vehicles being developed could also support the movement of cargo between two points on the Earth's surface.

Operation Elements

This section will cover the types of cargos that are expected to have the highest demand, and flight paths that can be used for delivery of goods by rockets. This section will conclude with an overview of the expected operation types that could be used to support the movement of cargo by rocket.

Type of Cargo

The initial demand for cargo delivered by rocket would most likely be for humanitarian, military, and medical deliveries. However, demand for industry critical parts would likely follow close behind. In the long-term, as prices drop due to economies of scale, then personal demand items to support the ultra-rich could be a possible outlet.

Humanitarian aid is critical in the early hours and days of a disaster. While aircraft are able to carry large quantities of supplies, many times local infrastructure (e.g., roads, airports, bridges, communication, etc.) have been disrupted which may slow the distribution of urgently needed supplies. The use of rockets to swiftly move relief supplies from a *hub* to a remote *spoke* landing area could provide lifesaving support in the early hours of a disaster.

The military has shown interest in exploring the use of rockets to support ongoing combat operations around the world, and rocket delivery of supplies as outlined previously could support this mission. In fact, the United States Air Force has requested a budget of $47.9 million in fiscal year 2022 to explore the possible use of commercial rockets to move up to 100 tons of cargo anywhere on Earth in an hour or less (Mizokami, 2021). Both orbital and suborbital flights could support this mission. Orbital pre-propositioned combat packages could be stationed in orbit for use anywhere on the world. This would require an assumption of demand and a constellation of on-station *warehouse* satellites that could be called upon when needed. However, orbital pre-proposition of supplies would be expensive and would require constant monitoring. Suborbital resupply missions may be a better option to support military operations. With suborbital flights, the demand and location would be known so a customized package of supplies could be quickly delivered.

For both humanitarian and military operations, the use of space transportation may be considered. In an emergency, where time is of the essence, governments, and to some extent non-governmental organizations (NGOs), become price insensitive.

The third type of demand would come from industry for the resupply of critical parts. For example, a drilling rig in remote Africa may have a broken part that has brought drilling to a halt. The air cargo industry already meets this demand; however, it could take several days for a part to be delivered by air depending on the remoteness of the location. Using rockets for delivery could cut the wait time from days to hours. This would allow a quicker return to operation, and reduce lost revenue.

The fourth-envisioned demand would be for the quick movement of emergency medical items such as organs and critical drugs (e.g., a rare snake antivenom). Rocket delivery of these types of cargo could provide lifesaving treatments around the world.

DOI: https://doi.org/10.15394/ijaaa.2022.1671

The final demand envisioned would be for personal demand items. This demand would be most likely very small and would only be satisfied in the long term, once the price of delivery could be substantially reduced. The cargo to support this demand would consist of specialized goods mainly for the ultra-rich, such as fresh caviar or sushi that could be rocketed in to a special event.

While the demand for transportation by rocket would encompass parts of what is now carried by air carriers, a modal shift from air carries to rocket transport would be very limited and consist of the types of cargos outlined in Table 2.

For the delivery vehicle size, a larger body would be needed to support the high volumes and weight of humanitarian and military aid, whereas smaller bodies would be needed to support demand of industry, medical, and personal demand items.

Table 2

Type of Cargo

Type	Details	Example/use	Advantages	Disadvantages
Humanitarian	Items needed shortly after natural disaster	Food, medicine, critically needed items	Fast response	Limited ability to deliver large volumes
Military	Supplies needed to support ongoing combat operations	Critical combat supplies	Fast response for immediate demand	Limited ability to delivery large weights
Industry (critical parts)	Replacement of critical parts needed for operations	Aircraft parts, industry parts	Fast response to allow operations to restart	Expensive, so must balance cost of delivery with lost cost due to shutdown (economic decision)
Medical	Emergency medical requirements	Organ transplant, drugs	Saving lives	Expensive, economic decision
Personal demand items	Items demanded to support special request	Critical personal items, caviar, sushi		Expensive and very limited use

Type of Flight Path

Table 3 shows the type of possible flight paths to support cargo delivery. Out of scope for this investigation are the subsonic, supersonic, or hypersonic flight paths within the atmosphere.

Table 3

Type of Flight Path

Type	Details	Example/Use	Advantages	Disadvantages
Suborbital	Does not reach orbit	More flexible than orbital	Demand is known, cheaper than orbital	Slower than orbital resupply
Orbital	Body stays in orbit until needed	Preloaded supplies needed to support various military or humanitarian aid scenarios	Pre-positioned supplies Fastener delivery of supplies	Demand is unknown, much more energy needed, continuous monitoring

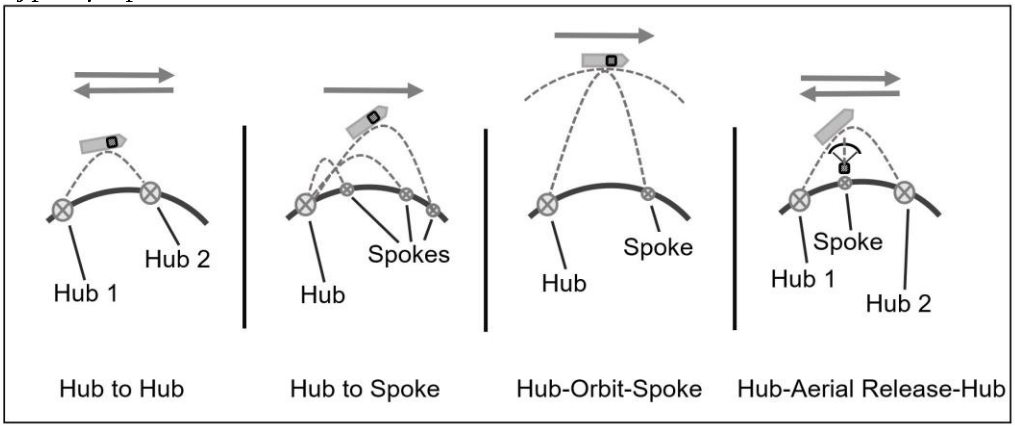
While a typical space tourism suborbital flight path is a steep parabolic trajectory (mission is to reach space efficiently, respectively just to go nearly vertical up to 100 km and down), a typical cargo suborbital flight path would be a relatively flat parabolic trajectory (mission is to reach a far distance destination efficiently). At first glance, existing space tourism suborbital vehicles looks like a good fit to be used, but these vehicles could only reach a few hundred kilometers and not thousands due to their limited fuel capacity. Existing discarded Intercontinental Ballistic Missiles (ICBMs) with a modified parachute system for cargo would also not be suitable due to the relatively bad environmental pollution footprint (fuel type, expendable parts, heavy, etc.) compared to today’s commercial state-of-the-art small launchers. Therefore, there is the demand for new development and/or modification of commercial small suborbital launchers to support future cargo transportation by rocket.

Alternatively to on-demand suborbital missions, there could be a chance for orbital missions consisting of pre-loaded supplies. Imaginable also is a coexistence in demand for both options. The preloaded supplies on several spacecraft parked in Low Earth Orbit (LEO) is comparable to fire extinguishers located in various places with the benefit of being ready to use if needed. The disadvantage of orbiting spacecraft is the need for replacing supplies once they expire, or the need to deorbit the craft due to the failure of sensitive parts. Existing spacecraft such as the Soyuz could only partly fulfill this mission due to the limited time of about a year that the system can stay in orbit before it needs to be deorbited. In conclusion, there is a demand for the development of a relatively small orbital launcher with a system allowing for return and precise landing at designated destinations.

Type of Operation

Like other modes of transportation, support infrastructure would need to be constructed, operated, and maintained. Currently there are a limited number of spaceports being operated, mainly in the United States. This network of spaceports would need to be expanded to meet demand and support cargo operations by rockets. The authors envision four types of delivery methods as illustrated in Figure 2 and outlined in Table 4.

Figure 2
Type of Operation



The first would be cargo operations between hubs or decided spaceports. In this scenario, rockets would operate between a series of spaceports, similar to the current aviation system of airports. Each spaceport would be capable of launching and receiving rocket deliveries. These spaceports would also be able to provide maintenance support.

The second scenario would be from a hub to an unimproved spoke location. In this scenario, rockets would be launched from a spaceport but would be capable of delivery of goods to the point of need, most likely an unimproved landing zone (e.g., parking lot, open field, etc.). This type of mission would be particularly critical to support humanitarian and military aid. The return of the rocket body would be by other modes of transportation back to a hub or at worst case, local disposal.

The third scenario requires that a rocket be launched from a spaceport and parked in orbit until needed. This pre-positioning of cargo would mostly be for larger quantities of military and humanitarian aid. At time of demand, these orbiting *warehouses* could be deorbited and landed at an unimproved spoke location. This would be the most expensive operation and would require continued operational monitoring of the rocket while in orbit.

The final scenario would be a launch from a spaceport, with cargo release in flight and return of the rocket body to a spaceport. This operation would require a complex cargo landing system to control the decent of cargo to the demanded location. However, an advantage of this method is that the rocket body would return to a hub location where it could be reused.

For all operations, there will be political and regulations policy requirements that would need to be met. Like aviation, rocket delivery of goods has a global reach, so policies and regulations should be propagated by an international organization such as the International Civil Aviation Organization (ICAO) or a newly created body to provide policy oversight.

In transportation, the environment footprint is typically stated in amount of fuel or CO_2 per pound/kg moved per mile/km. For the five modes of transportation (road, rail, ship, air, and pipeline), aviation has the highest carbon footprint. Rocket delivery of goods will have an even higher footprint than aviation; however, its use will be more limited than aviation so this will limit the total amount of CO_2 and other contaminates emitted. While rocket delivery will have a large environmental footprint, the lifesaving attributes of the quick delivery of cargo must be considered, especially in the event of medical, humanitarian, and military aid.

Table 4

Type of Operation

Type	Details	Example/Use	Advantages	Disadvantages
Hub to Hub	Launch and land at dedicated space ports	Normal supply	Infrastructure in place, body can be reused	Expensive infrastructure required, restricted to location
Hub to Spoke	Launch from dedicated space port to unimproved locations	Emergency supply (humanitarian operations)	Ability to deliver anywhere	Return of rocket body is difficult
Hub-Orbit-Spoke	Launch from dedicated space port, place in orbit for later demand	Storage in orbit	Immediate supply	Must know future demand, most expensive option
Hub-Aerial Release-Hub	Launch from dedicated space port, release cargo midflight, return to a hub	Emergency supply	Rocket body is returned to hub	Complex cargo landing systems, cargo landing system disposable

DOI: https://doi.org/10.15394/ijaaa.2022.1671

Discussion

As shown in Tables 5–7 we evaluated the cargo, flight path, and operation types according to effective assessment criteria for each category related to near-, mid-, and long-term views. This is a best guess approach, which is appropriate for this kind of high-level conceptual research, but gives a starting point for a more in-depth analysis in the future by a pool of experts.

Table 5 shows our forecasted demand for the various cargo types over time. We focus only on demand that is realistic in terms of volume/weight versus cost to transport cargo by rocket. Therefore, the niche market demand for rocket transport will be focused on customers who are willing and able to pay a premium for this very fast mode of transportation. The market for military, humanitarian, industry critical parts, and medical cargo is already existing and supported by the air cargo industry and this is expected to continue into the future; while personal demand cargo, which is also currently moved by aircraft, is retarded in the beginning and not expected to have a large demand in the future for transportation by rocket.

Table 5

Assessment of Expected Demand Change Related to Rocket Transport

	Short (0–25 years)	**Mid (26–50 years)**	**Long (>50 years)**
Cargo Type	**D**	**D**	**D**
Humanitarian	+	+	+
Military	+	++	++
Industry (critical parts)	0	+	++
Medical	+	++	++
Personal demand items	--	0	+

Note. D = demand is: ++ = very likely, + = likely, 0 = neutral, - = unlikely, -- = very unlikely

Table 6 compares the possible flight paths and their impact to fulfill the needs over time. Here, we evaluated according to the energy savings (e.g., how efficiently fuel is burned per kg cargo), environmentally friendly potential (e.g., what pollution reductions are possible), and mission suitability (e.g., how well is the match between cargo loads and handling routines).

Clearly, a suborbital flight path is superior in the early phase due to its simplicity. On the other side for sporadic use, the orbital flight path has its advantage of immediate supply without activating a (hectic) launch campaign on Earth, as everything has been already prepared and *just* the deorbit phase needs to be initiated. In the distance future, both paths will be available and needed to serve different cargo market demands similar to the coexistence of planned suborbital and orbital space tourism missions (Goehlich, 2005).

Table 6

Assessment of Flight Path-driven Timeline

	Short (0–25 years)			Mid (26–50 years)			Long (+50 years)		
Flight Path Type	**Eg.**	**Env.**	**M.**	**Eg.**	**Env.**	**M.**	**Eg.**	**Env.**	**M.**
Suborbit	0	-	++	+	0	0	++	+	+
Orbit	--	--	-	-	-	0	0	0	++

Note. Eg. = energy saving; Env. = environmental friendly; M. = mission suitability is: ++ = very likely, + = likely, 0 = neutral, - = unlikely, -- = very unlikely

As shown in Table 7 we evaluated the operation types according to their political, economic, and technical feasibility. We define the feasibilities as following (based on Goehlich, 2015):

- P (political): feasibility is enhanced if type facilitates certification process, limits environmental effects, avoids legal hurdles, and leads to acceptable insurance arrangements,
- E (economic): feasibility is enhanced if type promises to contribute to the cost-effectiveness of operation, a benefit for a profitable driven firm, fulfill expectations from investors, etc., and
- T (technical): feasibility is enhanced if type supports state-of-the-art, well known technologies and procedures, and easy to assess.

While technically feasible in the early phase, all systems suffer for either political (e.g., challenge for acceptance) or economical (e.g., challenge for a positive business case) aspects. With matured and accepted technology in the future, hub to hub and hub-aerial release-hub will benefit.

Table 7

Assessment of Operation-driven Timeline

	Short (0–25 years)			Mid (26–50 years)			Long (+50 years)		
Operation Type	**P**	**E**	**T**	**P**	**E**	**T**	**P**	**E**	**T**
Hub to Hub	++	--	+	++	0	++	++	+	++
Hub to Spoke	-	0	++	0	+	++	+	+	++
Hub-Aerial Release-Hub	-	--	0	0	+	+	+	++	++
Hub-Orbit-Spoke	-	--	-	0	0	+	+	+	++

Note. P = political; E = economic; T = technical; feasibility is: ++ = very likely, + = likely, 0 = neutral, - = unlikely, -- = very unlikely

Implications and Recommendations

To provide more detail on the operation of a space cargo network, and to help readers visualize our concepts, we have outlined four sample scenarios to use as examples of how rocket transportation of cargo could be used in the future.

Scenario 1: Hub to Hub - Medical - Suborbital

Scenario 1 will consider a hub to hub suborbital flight with a cargo of critical medical supplies. It is expected that this scenario can be realized in the short-term (within the next 25 years). In this scenario, critical medical supplies are needed at a distant location. Using conventional aviation air transport, the transport time between two distance locations (Washington DC to Sidney Australia, for example) could take up to 24 hours, or possibly longer. Suborbital flight could cover this distance in less than an hour. In the hub to hub model, only locations close to a hub could be serviced, so the distribution would be limited to these areas. The concept is that critical medical supplies would be loaded on a rocket at one hub and then launched into a suborbital trajectory and land at the destination hub. Currently, technology exist to return rocket bodies to the launch area, so this scenario envisions taking this capability one step further and having the rocket land in a vertical position at the destination hub. This would allow the rocket to be quickly serviced, refueled, and reused. To support this scenario, small rockets could be used since the cargo would be limited in size and weight. The use of smaller rockets would also reduce the overall cost of the transport.

Scenario 2: Hub to Spoke - Critical Parts - Suborbital

Scenario 2 considers the movement of critical industrial parts for a hub spaceport to a remote *spoke* location by suborbital flight. The remote landing locations are unimproved landing zones (e.g., parking lot, open field, etc.) with no dedicated infrastructure to receive or relaunch rockets. Once the rocket has landed and the cargo offloaded, the rocket body would have to be disposed of locally or returned by other modes of transportation back to a hub. The rocket would need to be designed to be offloaded without special equipment. Cargo in this category may consist of critical parts where delay in receiving would cause a company economic damage. For example, a part of a petroleum drill rig in remote Africa fails. The broken part has brought drilling to a halt and a typical air cargo resupply would take several days. Assuming the resultant downtime is costing the firm $100,000 per day, the decision to use rocket resupply would be an economic decision for the company. Shipping the part by air cargo will take three days and cost the company $300,000 in lost time, where suppling the part by rocket could be accomplished with hours. Therefore, if the cost of the rocket delivery is less than $300,000, it would make economic sense for the firm to use this method.

Scenario 3: Hub to Aerial Release to Hub - Humanitarian Aid - Suborbital

This scenario outlines the possible use of rockets to support humanitarian aid immediately after an event. The concept is that a humanitarian relief package would be launched from a hub into a suborbital trajectory. Once over the delivery site the package would be released from the rocket. The relief package would then enter a controlled decent delivering the package to the needed area. The cargo braking system would most likely be by parachute. The rocket would continue and land at the next hub for reuse. This delivery method would be similar to a military airdrop mission however using rocket delivery instead. The cargo can be delivered in the first critical hours after a disaster and before aircraft can be sent to the area. Technology to deliver the package to a small target area would need to be developed to ensure that the cargo landed near the needed location.

Scenario 4: Hub to Orbit to Spoke - Military Equipment - Orbital

The final scenario is the most expensive and difficult. The concept is to launch into a stable orbit a pre-positioned package of combat equipment. When demand arises, the rocket can be deorbited and land at an unimproved location. Due to orbital mechanics, several packages will need to be on orbit at any one time. This may also require movement of the rocket from one orbit to another which is a difficult task. Once the rocket lands, easy access to the cargo would be needed with no infrastructure or equipment. The US military is currently considering this option (Mizokami, 2021).

These are just a sampling of possible scenarios for the movement of cargo by rocket; however, there are many more that can be imagined. Current rocket technology is increasing with the entry of private firms into the space market. However, development of vehicles capable of economically carrying cargo between two points of the Earth's surface will need to be developed before any of these scenarios can be realized. Private firms are in business to make a profit; however, in the short term the only agencies capable of providing the capital needed are governments. Therefore, government funding will be required to develop the technology needed to support cargo movement by rocket. However, once developed, then free market forces will take over to establish a new industry and a new mode of transportation.

Conclusion

In answering our initial research question, *to what degree does the transportation of cargo by space vehicle make sense*, we conclude: Despite the overall positive trend of a robust space cargo market, we see two streams in these scenarios: (1) starting with the technical relatively less complex hub to spoke operation in the near-term that will be complemented with hub to hub, hub-aerial release-hub, and hub-orbit-spoke operations in the mid- to long-term, and (2) starting with highly specific, but sporadic, all types of cargo in the near-term with a trend in mid- and long-term for regular transportations but still highly specific loads. This coincides with our insight that the competitive advantage of space cargo transportation is filling the gap for a niche market characterized by critical highly specific loads, with a very short demand timeframe, and at unknown destinations. Further, we reckon that for most of our defined cargo types (in particular for medical items), there is a price inelasticity of demand and whether this worse pollution transportation mode, compared to other environmental friendlier modes, will be ethically tolerated. A possible thread could be losing valuable time in paper work to get the “go” for a new launch event.

Future research on this subject will be needed by a group of experts to verify the author’s best guess approach used in this research. This study should be considered an initial starting point to drive discussions and future research on the feasibility of using rockets to transport cargo on Earth.

Declaration of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This joint research has its origin in the Embry-Riddle Aeronautical University network and began in 2014. The authors gratefully acknowledge support from Embry-Riddle Aeronautical University. The views reported in this paper are those of the authors alone and not those of any institution. All errors and omissions that remain are the authors’ sole responsibility.

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