Highlights of GAO-22-105166, a report to congressional addressees

September 2022

TECHNOLOGY ASSESSMENT

Large Constellations of Satellites

Mitigating Environmental and Other Effects

Why GAO did this study

Enabled by declines in the costs of satellites and rocket launches, commercial enterprises are deploying large constellations of satellites into low Earth orbit. Satellites provide important data and services, such as communications, internet access, Earth observation, and technologies like GPS that provide positioning, navigation, and timing. However, the launch, operation, and disposal of an increasing number of satellites could cause or increase several potential effects.

This report discusses (1) the potential environmental or other effects of large constellations of satellites; (2) the current or emerging technologies and approaches to evaluate or mitigate these effects, along with challenges to developing or implementing these technologies and approaches; and (3) policy options that might help address these challenges.

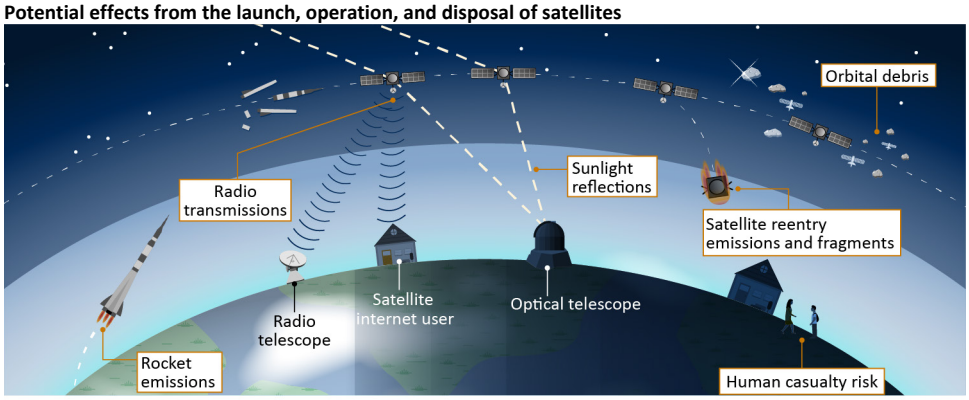
To conduct this technology assessment, GAO reviewed technical studies, agency documents, and other key reports; interviewed government officials, industry representatives, and researchers; and convened a 2-day meeting of 15 experts from government, industry, academia, and a federally funded research and development center. GAO is identifying policy options in this report.

View GAO-22-105166. For more information, contact Karen L. Howard at (202) 512-6888 or HowardK@gao.gov or Andrew Von Ah at (202) 512-2834 or VonAhA@gao.gov.

What GAO found

There are almost 5,500 active satellites in orbit as of spring 2022, and one estimate predicts the launch of an additional 58,000 by 2030. Large constellations of satellites in low Earth orbit are the primary drivers of the increase. Satellites provide important services, but there are potential environmental and other effects that this trend could produce (see figure).

Potential effects from the launch, operation, and disposal of satellites



Source: GAO. | GAO-22-105166
Note: Image not to scale.

GAO assessed technologies and approaches to evaluate and mitigate the following potential effects:

- **Increase in orbital debris.** Debris in space can damage or destroy satellites, affecting commercial services, scientific observation, and national security. Better characterizing debris, increasing adherence to operational guidelines, and removing debris are among the possible mitigations, but achieving these is challenging.
- **Emissions into the upper atmosphere.** Rocket launches and satellite reentries produce particles and gases that can affect atmospheric temperatures and deplete the ozone layer. Limiting use of rocket engines that produce certain harmful emissions could mitigate the effects. However, the size and significance of these effects are poorly understood due to a lack of observational data, and it is not yet clear if mitigation is warranted.
- **Disruption of astronomy.** Satellites can reflect sunlight and transmit radio signals that obstruct observations of natural phenomena. Satellite operators and astronomers are beginning to explore ways of mitigating these effects with technologies to darken satellites, and with tools to help astronomers avoid or filter out light reflections or radio transmissions. However, the efficacy of these techniques remains in question, and astronomers need more data about the satellites to improve mitigations.

GAO developed the following policy options to help address challenges with evaluating and mitigating the effects of large constellations of satellites. GAO developed the options by reviewing literature and documents, conducting interviews, and convening a 2-day meeting with 15 experts from government, industry, and academia. These policy options are not recommendations. GAO presents them to help policymakers consider and choose options appropriate to the goals they hope to achieve. Policymakers may include legislative bodies, government agencies, standards-setting organizations, industry, and other groups.

Policymakers may be better positioned to take action on this complex issue if they consider interrelationships among these policy options. For example, implementing the fourth option (improving organization and leadership) may improve policymakers' ability to implement the first and second options (building knowledge, developing technologies, and improving data sharing). Similarly, implementing the first option may help with the third option (establishing standards, regulations, and agreements). More generally, trade-offs between mitigations may emerge, the ongoing increase in new constellations may introduce unexpected changes, and a large and diverse set of interests from the global community may shift over time, all of which present persistent uncertainties. To address these complexities and uncertainties, the full report presents the policy options in a framework, which may help policymakers strategically choose options to both realize the benefits and mitigate the potential effects of large constellations of satellites.

Policy options for technologies and approaches to evaluate and mitigate potential effects of large constellations of satellites

Policy Option	Opportunities	Considerations
Build knowledge and develop technologies (report p. 57) Policymakers could support research on the extent of potential effects, as well as development of technologies to address them.	• Improving knowledge about potential effects of satellite constellations could help policymakers decide which mitigations to implement, if any. • Research on darkening satellites, removing orbital debris, and other technologies could lead to innovative mitigation.	• Resources for studying the potential effects of satellite constellations are limited, in both the government and private sectors, which could hamper efforts to build knowledge or develop technologies. • Knowledge of some effects, such as the long-term growth of orbital debris, may already be sufficient. Experts told us that in such cases, leadership and standards, regulations, and agreements could prompt action.
Improve data sharing (report p. 57) Policymakers could facilitate improved sharing of relevant data about satellite constellations.	• The ability to more easily share high-quality data could improve mitigation of potential effects. For example, better satellite position data might help astronomers avoid disruptions or help satellite operators avoid collisions. • Increased data sharing may create opportunities for increased collaboration and awareness across government, academia, and the satellite industry, which could in turn generate additional mitigation approaches.	• The ability to effectively share data will depend heavily on the willingness of stakeholders, particularly satellite operators. Some operators are willing to share data with entities that have a demonstrated need but expressed reservations about sharing certain detailed data more openly. • Collecting and updating data on satellite positions or other key information in a common format poses technical and logistical hurdles.
Establish standards, regulations, and agreements (report p. 58) Policymakers could establish appropriate standards, regulations, and agreements to help mitigate potential effects of satellite constellations.	• Establishing formalized standards, regulations, and agreements around potential effects of satellite constellations could help institutionalize successful mitigation approaches and make them standard practices for future operators. • Formalized regulations could provide enforcement avenues to help protect existing satellite operators and stakeholders and provide direction to new entrants.	• Regulations on satellite licensing or operation may create incentives for operators to pursue licensing in less-regulated venues. • Authors of voluntary standards and agreements might face difficulties incentivizing private operators to adopt new practices. • Existing laws and accepted practices vary across domains. For example, international law may only address certain types of effects.
Improve organization and leadership (report p. 59) Policymakers could build national and international organizational and leadership structures that facilitate effective mitigation of the potential effects of satellite constellations.	• Centralized leadership and coordination may improve mitigation. • Broader organization and leadership structures could pull together relevant stakeholders to implement mitigations.	• Unilateral leadership or mitigation action by one nation could cause satellite operators to license in less-regulated nations. • International agreements on satellite constellations may take longer to implement and may lag behind the need for timely mitigation. • Establishing effective organization and leadership structures may divert resources and personnel from other missions.

Source: GAO. | GAO-22-105166