K2UPG01 - Konstruktions och tillverkningsprocessen
Woodrow Wiest

Rocketdyne F-1 Engine

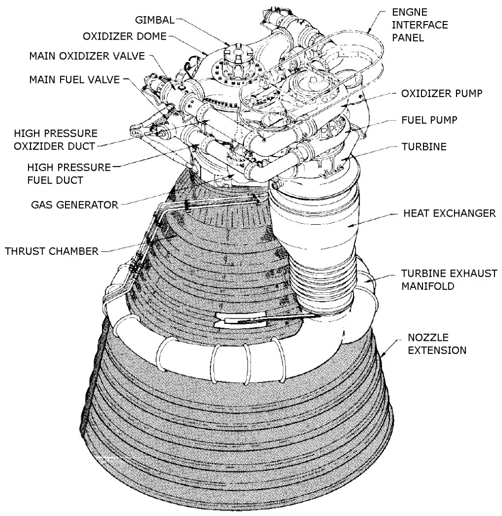


Fig. 1. Here we see some of the complexity of a launch vehicle engine. Credit NASA.

Bakgrund

Space allows for faster communication amongst people around the world, advances in science and understanding of our origins, opens up the possibilities of new manufacturing techniques, and continues to ignite the human passion for exploration. The entryway to space is the launch vehicle. This vehicle has been extremely complex, prohibitively expensive, and difficult to manufacture because the vehicle must sustain some of the most extreme stresses and constant changing environments during its life.

Traditional manufacturing has progressed over the centuries with technologies constantly improving we are now capable of creating increasingly complex products. This complexity has come at a cost. A more complex product typically requires more complex tooling, more complex tooling becomes increasingly difficult to produce and, with the exception of manufacturing at scale, much more expensive.

Completed Saturn V rocket

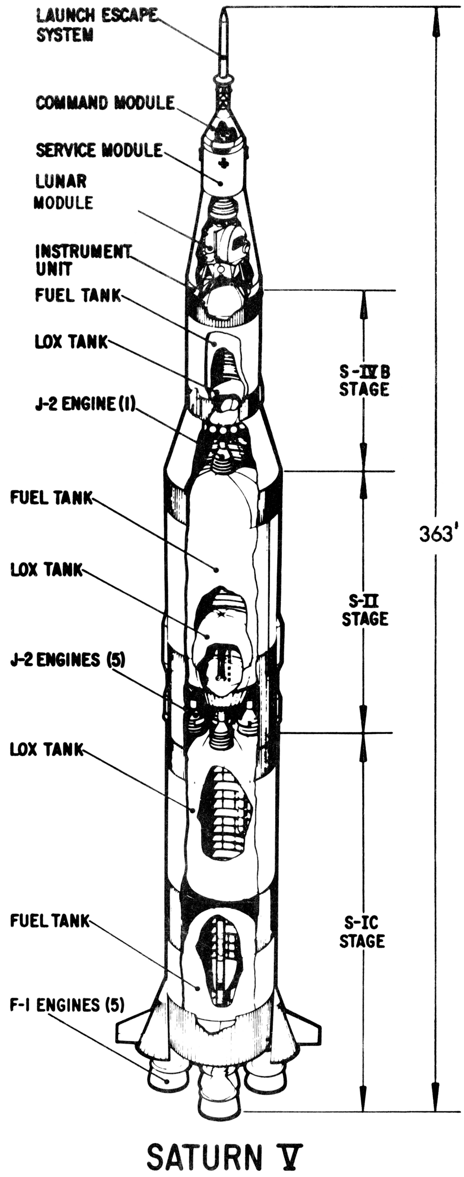


Fig. 2. Here we take note of the complexity and thousands of parts that must be manufactured by traditional manufacturing methods for a complete Saturn V launch vehicle. Also see the more detailed sketch at the end of this document. Credit NASA.

Syfte / Mål

Produce a launch vehicle capable of handling the stresses of reaching orbital flight and payload deployment. Compare and contrast a traditional manufacturing technique and the basic methods involved to a similar finished product made primarily with AM.

Here we will take an overview approach and attempt to understand the difference between additive manufacturing and traditional manufacturing. We will describe how the process differs between additive manufacturing and traditional manufacturing and show some of the benefits that AM brings to the table.

Specifikation

Pointy end up, flames out the bottom, rocket goes up, must be strong enough to avoid rapid unplanned disassembly, put x amount of payload into orbit and do this as cheaply and simply possible.

There are some very specific thrust to weight ratios and the tyranny of the rocket equation(mass limitations), physical limitations and stresses which will need to be considered here. Material choices will be reliant on their respective properties and their ability to withstand the above stresses. Some materials available are Aluminium honeycomb reinforced composites for lightweight yet stiff structures like fairings and interstage, carbon fibre for propellant and other pressure vessels, metal alloys for high stress tolerance and flexibility in engines, polymers for non structural applications, and ceramics for thermal shielding.

Utkast / Idé-skiss

An overview sketch is required of the complete vessel. More detailed various modeling is required for each component (pressure vessels, engine components, control system) as well as means of interconnectedness of components.

Design / Konstruktion

Knowledge of manufacturing techniques of each material is required to design and optimize the component for manufacture. Carbon for pressure vessels must be wrapped, cured, and removed from moulds. Engine components must be individually designed to be fabricated and assembled. Carbon composites must be designed to be built systematically to reduce amount of complex curvature to accept the honeycomb core, glued and cured. Special care must be taken during design in respect to thermal properties and interoperability of parts.

Beredning

Tooling for each part must be prepared: Moulds for carbon, composites and casting, machine tools to convert raw materials into finished metal parts. Special care must be taken to optimize the finish and fit. Special cradles and other support for the connection of large parts must be made.

Tillverkning / Efterbearbetning

Casting produces complex specialty parts through pouring liquid metal into moulds. Cast parts must be removed from moulds and surfaced for connecting to other parts. CNC lathes and mills produce components out of solid metal by removing unwanted materials revealing the finished parts. Carbon composites are built up layer by layer systematically over a mould and baked in a vacuum environment for curing. Moulds must be removed, excess material must be cut away and fittings installed to connect to other parts. Much metal tubing is produced by extrusion for other propellant delivery.

Kvalitetskontroll

Constant measurements and quality control is carried out during the entire process from design to manufacture. After manufacture of each component comes the pressure testing of pressure vessels, test firing of engines, shock-load and vibration testing. After final assembly similar tests as listed above are conducted to ensure a safe and functional vehicle.

Leverans / Montering

The finished vehicle is moved to the launch platform and propellant loaded in preparation of launch.

Hur skulle Additiv tillverkning kunna påverka ovan beskriven process?

What was once only a sci-fi dream of pressing a button and having a product appear before our eyes is becoming a reality. Traditional manufacturing often starts with a hunk of raw material and chops away at it until the finished product is remaining. Building of moulds and forms are used to pour liquid metal into which then must be removed and dressed before the final product is available. Dies must be machined before injecting a material into them and removing the part. While there will still be a place for traditional manufacturing techniques, the potential for additive manufacturing to fill our future needs seems almost limitless.

Currently a vast array of manufacturing techniques are used in the manufacture of an orbital launch vehicle. Casting, machining, composite construction and tubular extrusion are some of the more common techniques. All of these processes require much design and preparation before the part is manufactured and then each part must be fitted to another part before the launch vehicle is complete. This process can take months or years to complete and often requires very special tooling, competence and many human labour hours to produce. All of this leads to higher complexity which leads to higher costs. AM has amazing potential to streamline this process by reducing part count, increasing design flexibility, and reducing costs.

Terran 1 Engine

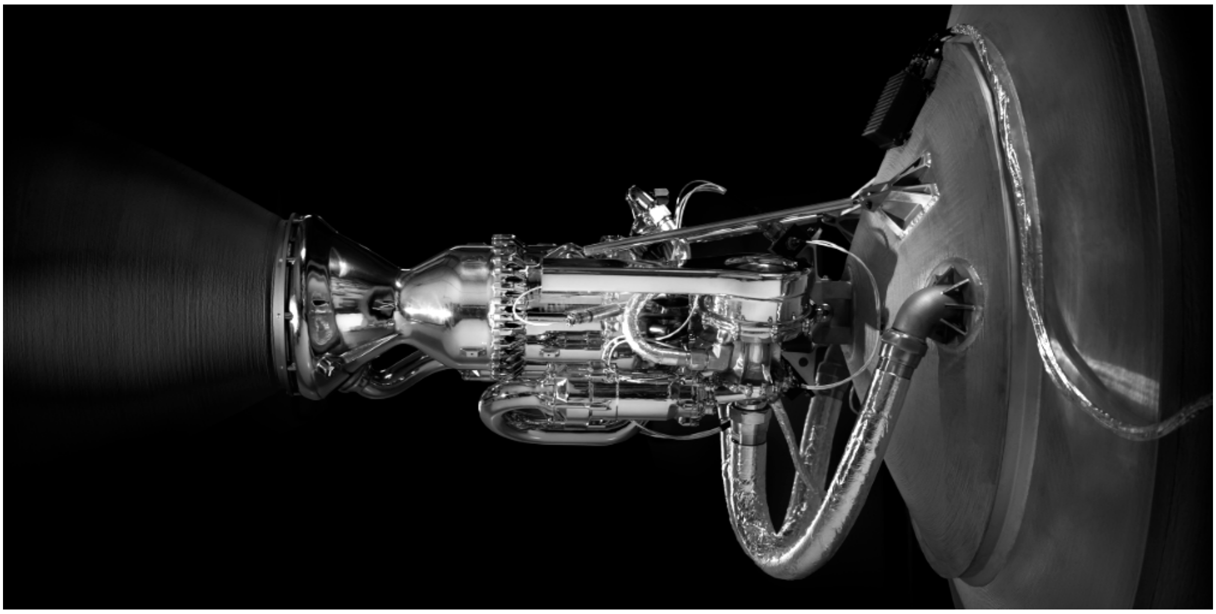


Fig. 3. While in a different class than the F-1 engine we can clearly see the reduced part count on this mostly 3D printed Terran 1 Engine by Relativity Space. Credit Relativity Space.

Reduced Part Count and Complexity advantage.
AM allows for increased part complexity. The part count can be reduced from thousands to hundreds by reducing the needs for fasteners and complex machined parts which must be fitted together after fabrication. Pressure vessels can be printed with supports and propellant delivery systems built in. Engines are full of specialty components and fluid cavities, all which can be optimised to become a single structure under AM.

Increased design Flexibility and Quick turnaround.
Traditional manufacture benefits from high volume manufacturing. The manufacturing cost per part typically can be reduced exponentially when producing high volume with the opposite effect happening with low volume. The space launch vehicle industry is a low volume industry. Furthermore, the mathematics of calculating vehicle stresses are extremely complex and very difficult to simulate accurately therefore constant design and testing iterations are needed. AM excels with its ability to produce flight capable parts after slight iterative changes.

Flexible production location and automation.
One very exciting possibility with AM versus traditional manufacturing is its ability to manufacture anywhere, California, Kiruna, in earth orbit, or even on Mars. Reducing part count and manufacturing techniques allows the process to break free from traditional tooling and size limitations. Manufacturing in space by robotic means will open doors to new design concepts and strategies that seem limitless.

Printing the Pressure Vessel

Fig. 4. Relativity Space has developed specific printing technology in order to print pressure vessels for propellant. Credit Relativity Space.

Reduced costs and a more capable final product.

Reduced part count, streamlined design to fabrication and flexible production location allows for the potential reduction in cost of labor, tooling, manufacture and transport. Furthermore, mass is one of the most expensive parts of a launch vehicle. For example in 2017 it could cost NASA as much as 80,000 USD to launch one kg to low earth orbit[1]. We can see how reducing mass is a key goal in launch vehicle design. AM can achieve a reduction in mass by designing the strength only where needed and leaving out unnecessary material or building special mass saving structure into the vehicle. Furthermore, quick iteration allows for more testing which leads to more improvements which leads us to a more capable final product.

Övrigt / Fri skrivning/ Kommentarer / Bilagor

I approached this assignment as an overview. Realistically on our classroom scale we will be working with individual parts instead of whole systems. Individual parts of each launch vehicle will benefit from AM but I feel it is important for me to reconsider the system holistically to best utilize the current strengths of AM with respect to this field.

Referenser

List of figures:

Fig. 1. NASA, Rocketdyne F-1 engine, http://history.msfc.nasa.gov/saturn_apollo/documents/F-1_Engine.pdf, Public Domain, https://commons.wikimedia.org/w/index.php?curid=5719665]

Fig. 2. http://heroicrelics.org/info/saturn-v/saturn-v-general/saturn-v-apollo-4-press-kit.jpg

Fig. 3. https://smallsatnews.com/wp-content/uploads/sites/11/2020/06/Relativity-Terran-1-engine.jpg

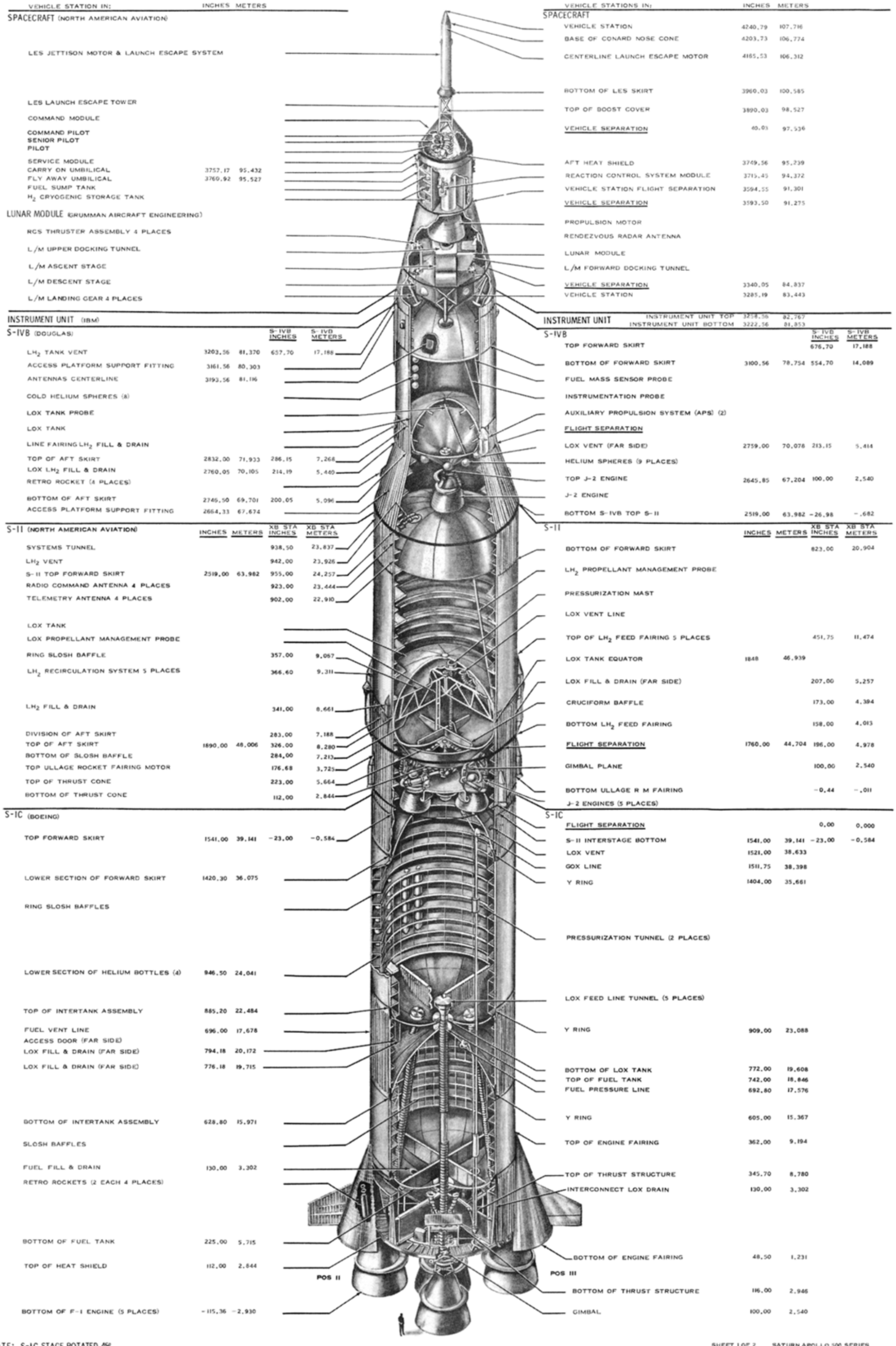
Fig. 4. https://cdn.arstechnica.net/wp-content/uploads/2019/01/tank1.jpg

Fig. 5. https://nasa.gov

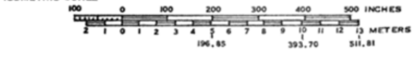
Sources:

Zapata Edgar, The State of Play - US Space Systems Competitiveness, NASA, 2017, p.13, https://ntrs.nasa.gov/citations/20170012517

SATURN V APOLLO FLIGHT CONFIGURATION



NOTE: S-IC STAGE ROTATED 45°
COUNTER CLOCKWISE
FOR CLARITY



SHEET 1 OF 2 SATURN APOLLO 500 SERIES

THE **BOEING** COMPANY
SPACE DIVISION, LAUNCH SYSTEMS BRANCH
HUNTSVILLE, ALA 35807

SATURN V APOLLO
FLIGHT CONFIGURATION

THE ***HEROICRELICS*** WEB SITE
RELICS OF THE HEROIC AGE OF MANNED SPACE FLIGHT

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