RAPPORT – Loket5

Renderade Bilder och Fusionlänk (G)

LOK Assembled - https://a360.co/3vkc56W
LOK Body - https://a360.co/3eBzzie

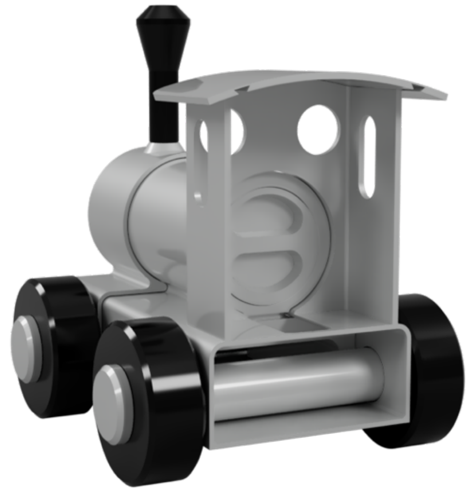

Figure 1 – Rendering. Fully expanded and assembled locomotive rendered in Fusion 360. Note dovetail joints on the aft edge of the cabin roof and threaded cap in the boiler.

Bilder på utskrifter (G)

Figure 2 - All pieces after printing with brim and support material removed. Note full original length of cabin roof. The sliding mechanism can be seen here on the underside of the roof.

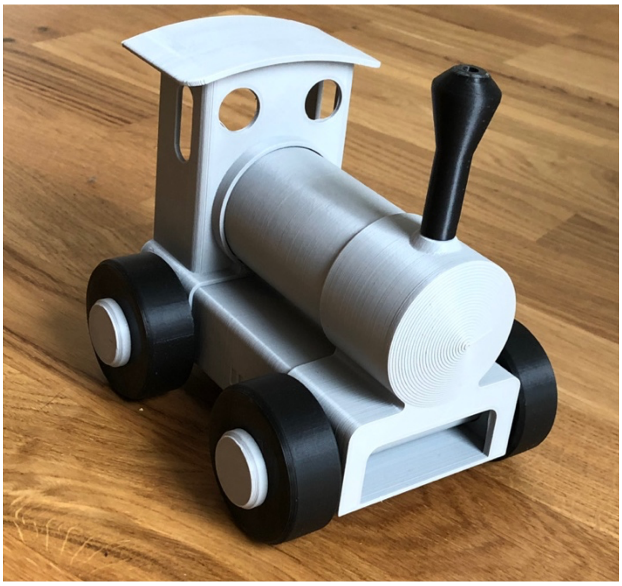

Figure 3 - Fully assembled LOK5. Note how the main body of the locomotive is fully extended in a telescoping fashion. The roof slides aft as well, maintaining complete overall dimensions of original LOK design.

Parametrar för ”slicing”-program (G)

Printer	Ultimaker 2+
Bed surface	Glass
Nozzle	0.4 mm
Material	add:north X-PLA Light Grey and Black
Slicer	Ultimaker Cura 4.8.0
Hot end temperature	193 °C
Bed temperature	66 °C
Ultimaker print profile	Extra Fine (plus changes listed below)
Layer height	0.25 mm
Wall thickness	1.05 mm
Infill density	20%
Infill Pattern	Cubic for batch1, triangle for batch2
Speed	50 mm/s
Support	Only with batch1
Build plate adhesion	Brim, Purple glue stick

Tabel 1 – Slicer settings

Omdesign enligt förutsättningar (G)

This locomotive is a redesign of LOK4. The assignment requires combining several parts of the LOK4 into one while maintaining the look and dimensions of the original locomotive design.

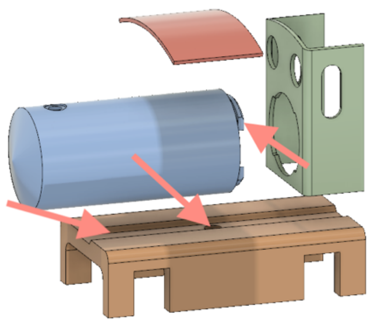

Figure 4 - Components of original LOK design. Arrows noting which features are to be deleted before combining. Components separated and colored for clarity.

Conditions

- Maintain original design dimensions for final assembled locomotive.
- Combine boiler, cabin, roof, and chassis.
- Remove the need for locking bridge and screw.
- Parts must be printable with FDM.
- Wheels must be free to spin.

Combining parts – Maintaining dimensions

I have taken some artistic liberty when merging the chassis, boiler, cabin and roof *(fig 1 through 3)*. My goal is to create and interesting spin on the design to make use of the increased complexity allowance of the FDM 3D printing process.

The merged components are designed collapsed into themselves *(fig 2)* when printed, expand and lock in place automatically with small offset nubs for final assembly *(fig 1 and 3)*. The print has a smaller print volume but greater complexity and uses slightly less filament compared to LOK4.

The cabin roof is also printed as a merged component. The aft section of the roof overhangs beyond the end of the chassis in the original design. I designed the roof to be printed full size and slide aft 10 mm after printing to maintain the same overall final dimensions *(fig 2 and 3)*.

Without the locking bridge and screw to hold them in place, the axels and their attachment style to the chassis, have been redesigned. See figure 7 and Anpassningar (VG) for further details.

The chimney and wheels remain unchanged and are consequently interchangeable with LOK4.

Making the design printable with FDM

In order for this complex merged design to print properly special care has been taken to ensure tolerances of at least 0.2 mm between all printed surfaces that are needed to clear each other during assembly. These surfaces include wheel and axel, threads to the chimney and boiler cap, sliding cabin roof flanges, telescoping boiler and stopping nubs. More information on tolerances and print tests can be seen under Anpassningar (G) and (VG) sections below.

Anpassningar (G)

Combine components

Merge cabin, roof, chassis and boiler into one component *(fig 6)*. This is accomplished quite simply by selecting and deleting faces *(fig 4 and 5)* and merging the bodies with the combine command. This is accomplished so easily and quickly so I have decided to make this project more difficult by designing a combined telescoping body instead *(see Telescoping Body under Anpassningar VG).*

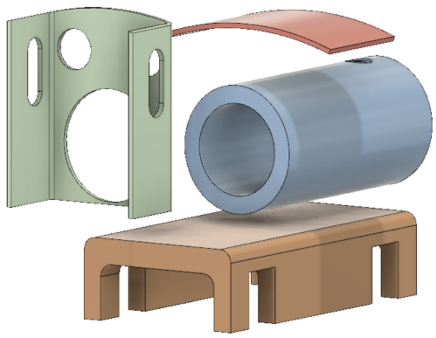

Figure 5 - Features deleted in preparation for combining the components into a single body. Bodies separated and colored for clarity.

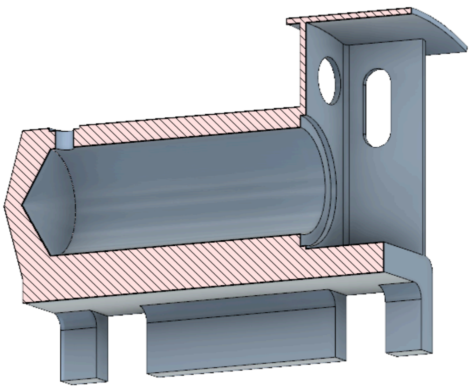

Figure 6 - Cabin, chassis, boiler, and roof fully combined. Note removal of threads and holes to the locking bridge screw.

Redesign axel connection to chassis

Remove the need for the locking bridge and screw by redesigning the axel to body connection. This is accomplished by removing the axel cutouts in the chassis and replacing them with holes to accept the axels *(fig 7).*

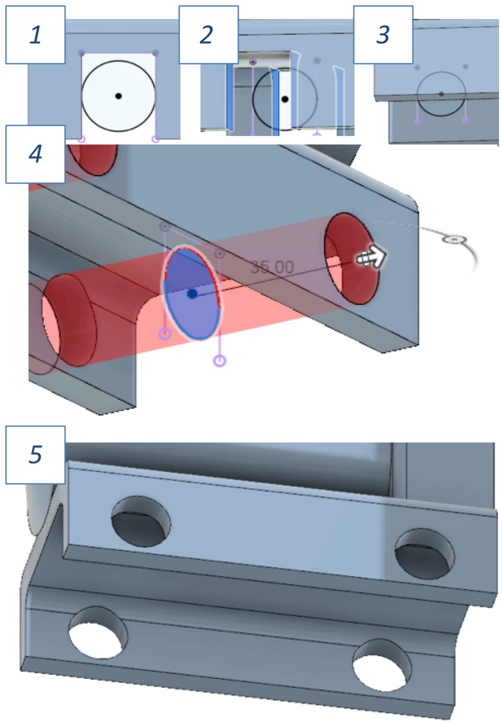

Figure 7 - Detail of steps taken to convert axel-slots in chassis to axel-holes. 1- create sketch, project edges and draw circle. 2- select faces. 3- delete faces. 4- extrude cut. 5-finished body.

Test prints

This design will require a few test prints to ensure the parts fit, however, we are nowhere near ready to begin test printing as many more changes adaptations to the design are required first. Test prints will be covered under Anpassningar (VG) below.

Kalkyl Loket 5 Verklig kostnad FDM (G)

Typ av kostnad	Totalpris
Kostnad operatör + maskiner	kr 1 881
Kostnad material	kr 135
Ändringar anpassningar	kr 5 575
Tests Operator + machine	kr 572
Test materials	kr 3
Totalt	**kr 8 166**

Kalkyl Loket 5 Uppskattad kostnad för FDM (G)

Simple and cheap	
Typ av kostnad	**Totalpris**
Kostnad operatör + maskiner	kr 1 881
Kostnad material	kr 135
Ändringar anpassningar	kr 1 325
Tests Operator + machine	kr 141
Test materials	kr 3
Unknown costs 10% of final	kr 348
Totalt	**kr 3 833**

Advanced and expensive	
Typ av kostnad	**Totalpris**
Kostnad operatör + maskiner	kr 1 881
Kostnad material	kr 135
Ändringar anpassningar	kr 4 575
Tests Operator + machine	kr 572
Test materials	kr 10
Unknown costs 10% of final	kr 717
Totalt	**kr 7 891**

Anpassningar (VG)

Telescoping Body Assembly

Combining and preparing the boiler, cabin, chassis and roof for print *(fig 6)* lacks sufficient challenge. Therefore, a decision has been made to complicate the assembly with the goals of decreasing build volume and increasing the coolness factor beyond the original assignment objectives. To reduce the build volume, the chassis-boiler-cabin section will collapse in on itself in a telescoping fashion and the roof will be on a slider so it can fully extend after printing. This requires a significant amount of CAD modifications.

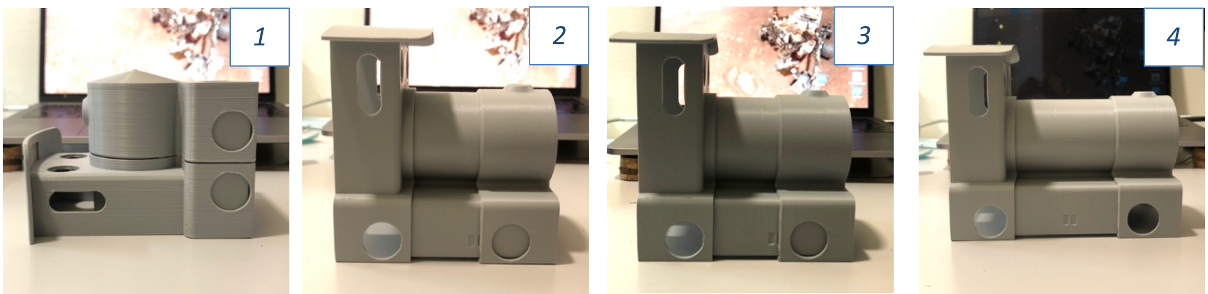

*Figure 8 – 1, body after printing. 2, forward section extended. 3, roof extended. 4, fully extended. Note small recesses in the midsection, this is where the tabs secure when body is collapsed. The fully extended body is secured in similar recesses *not seen.*

Telescoping boiler

The boiler-chassis-cabin body is cut into sections, keeping the original in one piece for reference. The split body is used as tools to design the telescoping action by offsetting faces, using the combine tool to remove material so the whole assembly is nested together. Small tabs and recesses are added to the chassis sides and top of boiler so the telescoping action will click together when closed or extended *(fig 8)*.

Sliding roof

To maintain the same final overall dimensions, the roof is designed with dovetail joints *(fig 1 and 9)* to facilitate a sliding action after printing *(fig 8)*.

Chassis reinforcement

Material is removed from the forward and aft chassis section near where the axel is inserted. In order to maintain strength and durability, the chassis is reinforced by connecting the port and starboard sides of the body as seen in figure 9.

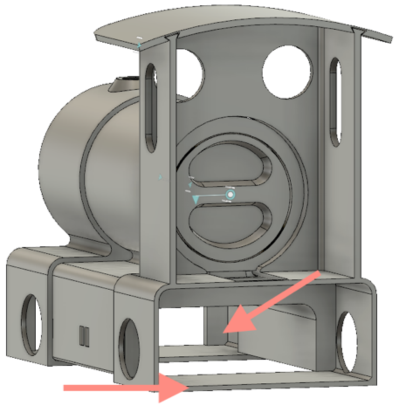

Figure 9 - Reinforcements noted with red arrows. Roof dovetails and boiler cap visible.

Cap

The cap *(fig 9)* is an extra addition beyond the design requirements. It does not change the overall dimensions of the locomotive and requires very little material. I like the form and function of the cap, but it can be omitted easily if desired. The cap is designed to print in place with the rest of the body. In Fusion 360, inner and outer threads are not normally modeled in such a way that allows for threads to be printed successfully *(fig 10)*. To get around this, the threads were modeled on the cap and the cap is used as a tool with the combine command to cut the threads from the inside diameter of the boiler in the exact position as the cap. Offsets are then applied to all faces of the threads to allow for at least 0.2 mm clearance as required by the FDM process.

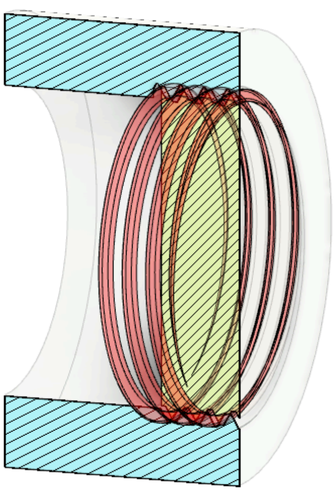

Figure 10 - Section analysis of modeled thread interference captured from Fusion 360. The red color indicates overlapping bodies.

Axels and Hubs

The portside hub has been merged with the axel. Internal threads have been added to the starboard side of the axel and external threads added to the starboard hub to lock the wheels and axels to the chassis *(fig 11)*. The assumption is that the train will spend more time rolling forward than reverse, so the threads are both on the starboard side and are right-handed to prevent threading loose during rolling forward. There is typically enough friction with PLA threads to prevent this and there is extra tolerance designed into the axel length to allow minimal friction of the wheel against the hub.

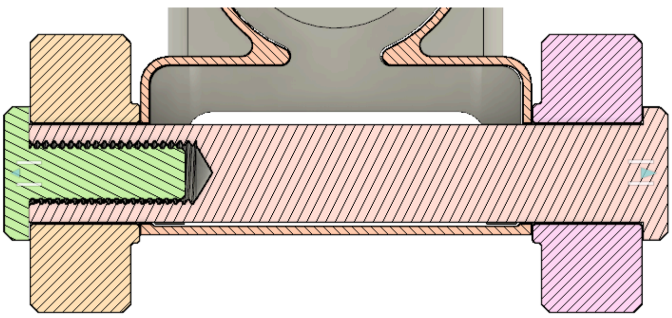

Figure 11 - Section analysis of forward axel-hub-wheel-chassis assembly. Note thread interference on modeled threads.

Chimney

The chimney remains unchanged from the previous design, but because of the telescoping action of the boiler, there is no longer enough threads remaining for a secure connection. This is remedied by adding a chimney-boss offset from the boiler, modelling threads, and adding a chamfer for good looks *(fig 12)*.

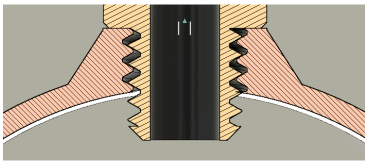

Figure 12 - Chimney boss.

Fillets and Chamfers

The second to last step after all of the main changes are modeled is to add fillets and chamfers everywhere. Between the boiler and chassis fillets are added for extra support and on the forward corners of the roof for good looks. Chamfers are added to the inside bottom of the chassis for extra support. Care is taken to ensure if a fillet or chamfer is placed near an edge where there may be interference, an opposite fillet or chamfer is also modeled. *(see fig 13)*

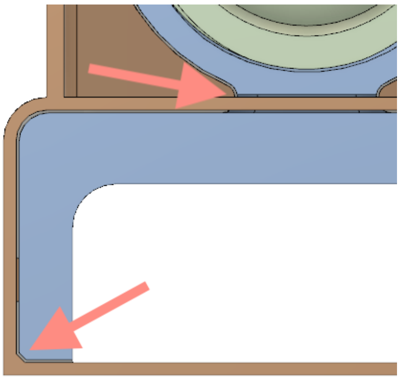

Figure 13 - Fillets, chamfers and tolerances. Red arrows note where fillets and chamfers require opposites to be modelled. The faces are colored to accent the tolerances modeled for successful printing.

Tolerance

Based on previous experience with FDM 3D printing, at least 0.2 mm of tolerance needs to be modeled between any part that is required to fit within another part and still have freedom to move unhindered. Special care is taken to add all required tolerances now as the last step in modelling before test printing.

Test prints

This complex design requires careful consideration with respect to tolerances so that all parts can move freely during assembly while maintaining strength after assembly. Several test prints are required to realize the capabilities of the printer and validate the design. A copy of the finished CAD model is created to be cut up for testing. The tests will be printed using the final print settings as listed in table 1.

Main body tolerance test

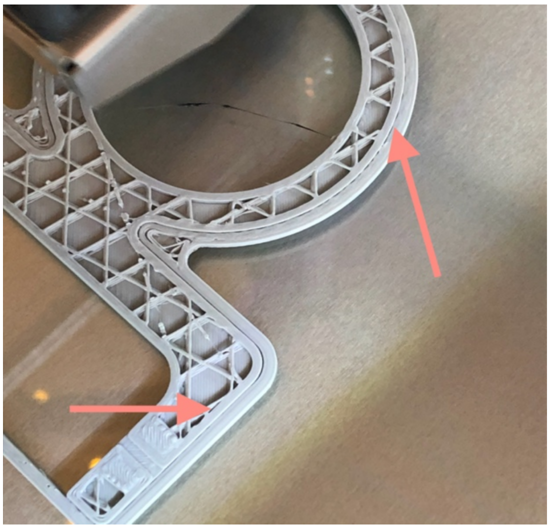

Figure 14 - Too close for comfort.

The first test *(fig 14)* designed is to test the main 0.2 mm modeled clearance. This test showed 0.2 mm was not enough allowance for this Ultimaker 2+. The finished test piece was fused together. The next test, as seen in *figure 15,* is with 0.3 mm modeled clearance which is adequate. The second test showed an issue with the two pieces of the base of the telescoping boiler fused together. This is remedied by removing the axel notch. It was put there only for aesthetic purposes but is not seen when the locomotive is fully assembled therefore not needed.

Axel/Hub/Wheel test

This test *(fig 15)* is to ensure the wheel fits onto the axel and spins freely, the axel fits into the chassis and the hub screw fits into the axel to hold the wheel and assembly together. The test was created by removing a section of the axel, discarding it and merging the threaded and hub sections back together to create the test. The hub screw is relatively small with little material use. I am confident it will print properly so I print the entire piece. That way I will not need to print it again when it fits. This requires the threads to be modeled straight through the hub of the test axel which consequently saves material on the test axel.

Figure 15 - First three tests. Top right, fused first test. Bottom left, acceptable 0.3 mm tolerance. Bottom right, axel-wheel-hub test.

Body support, clips, sliders and threaded cap test

This is the most difficult of the three tests to design. It could be a bunch of small tests; however small tests would not show enough motion to accurately show the sliding motion or give an accurate rigidity example for us to be sure the clips lock into place and defect out of place. Tolerance of the cap threads should be tested as well.

The parts to be tested are all relatively close to one another in the model. If thinking about the final print orientation, these parts will fall within the first ten millimeters of the print. I could cut the model at 10 mm for a test print, but that would not account for the deflection of the clips and the sliding telescoping action test. In this case I have decided to start the print as If I would be making the final print. I will watch the first three to six layers print paying close attention to tolerances of the threads and cabin roof sliders, bed adhesion and support clearance *(fig 16)*. If these things look ok within the first ten millimeters then I feel comfortable allowing the entire print complete knowing that there is still a very small possibility for failure in certain sections, for example where the fore and aft sections of the telescoping body overlap.

The support interface to the cabin is the last location of concern. Returning to watch the print at that point is the second part of this test *(fig 17)*. If the support interface is unacceptable, I will stop the print, otherwise the print will continue, and filament will be saved in the process.

Figure 16 - Acceptable final test.

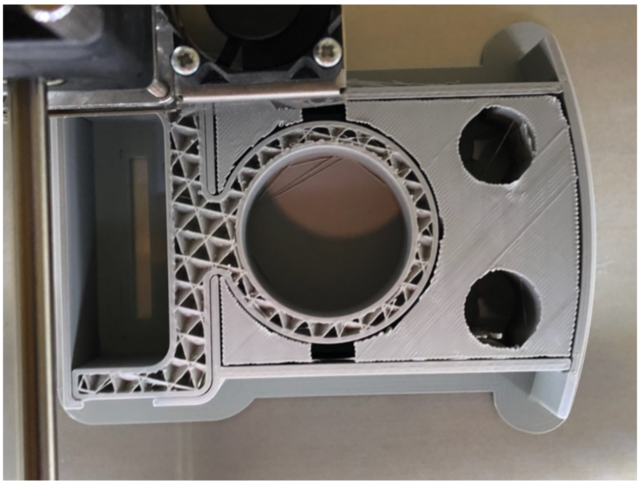

Figure 17 - Acceptable support interface.

The weight of filament required for this complete print is 138 grams, which is a cost (48 SEK) much lower than if I were to mess around in CAD for two hours (1 000 SEK) creating a half dozen test prints. Even if this test print were to fail near the end, losing all material and printer time, I would consider it successful because that print will contain all of the tested tolerances allowing me to make changes easily.

Jämförelse Loket 4 / Loket 5 (VG)

The real cost for **Loket 4** came to **3 906 SEK** and the Real cost for **Loket 5** came to **8 166 SEK**. If I followed the assignment more closely the final costs of loket 5 could be as low as the **3 485 SEK** estimated cost.

Time and Changes

The sole reason for the cost discrepancy between the two print jobs is simply the amount of CAD hours required for modeling the fancy telescoping combined cabin-boiler-chassis-roof component. There was **1,48 hours** of billable CAD on loket 4 compared to **11,15 hours** on loket 5.

If we consider the simple version, loket 5 would have only consumed 2,65 hours of CAD time. I am confident this estimate can be considered accurate to real world time because I timed myself making these cad changes. I was interested to see the difference between the advanced and the simple design and I wanted to get some screenshots of the simple changes for this report. Now that I have experience completing the advanced telescoping design, I feel like I could definitely shave some hours off of it for next time, lowering the costs to potentially 6 000 SEK.

Material Consumption and Cost

I am not surprised when I see that the final weight estimates had **loket 4 weighing 558** grams with **loket 5 weighing 442** grams. The redesign just takes less volume, using less support material and less infill.

Finishing and Assembly

It took less time to post process loket 5 because there were simply less parts to post process. There was also less support material required due to the smart redesign.

After post processing, assembling loket 5 was very easy but took about the same amount of time as loket 4. Only seconds were saved here as there are still threads and pieces to assemble. If there were thousands of parts, this might amount to a number more significant, but if there were thousands of locomotives being produced, I might have redesigned differently to make it faster or take less steps to assemble.

Reflektion Loket 3 (VG)

The estimated cost to produce **Loket 3** with traditional machining came to **16 694 SEK**. Even with my ten hours of CAD redesign time on the advanced telescoping body, **Loket 5** came out at half that cost.

The main reason for the cost discrepancy between Loket 3 and 5 comes down to the many working operations, machine and human hours required to traditionally machine the locomotive. Planning and preparing every machine in the traditional sense takes time. It could be argued that each machine operation takes roughly the same amount of planning, but each machine requires a skilled operator to carry out the task. With additive, there is only one machine performing all of the operations.

Material consumption plays a role in the increased cost of traditional manufacturing. Traditional manufacturing is a subtractive process where the part starts out as a larger piece of material and cutting tools chip away at that material until the final piece is finished. This requires more material to begin with, which also means there is a significant more material wasted than with additive manufacturing.

Övriga reflektioner (VG) Skriv fritt

Lok4 vs. Lok5

Lok 4 was printed as true to design as possible. Every part only adapted slightly by adding tolerances and allowances directly into the CAD model to enable the printed parts to fit without any need for adjusting post print. This posed some specific challenges to the printing process especially when considering strength and support structure requirements. The boiler bayonet flange, the axel-end flanges and the hub flange are all weak points in the design. Those areas are thin and when printed level with the Z axis the strength is reduced considerably. This can be remedied slightly by adjusting the print orientation but the consequence of that is the increased support material requirement and a poorer surface finish after the support is removed.

Lok 5 allowed for us to change the design to such an extent to remove those weak points and replace them with our own, hopefully improved, designs. In Lok 1 I redesigned the axel to nav connection to be stronger and better suited for PLA printing. The connection was very similar with the hub attaching using a sliding action. The hub, instead of being round with very little surface area between the printed layers, was modeled the full width of the axel *(fig 18)*.

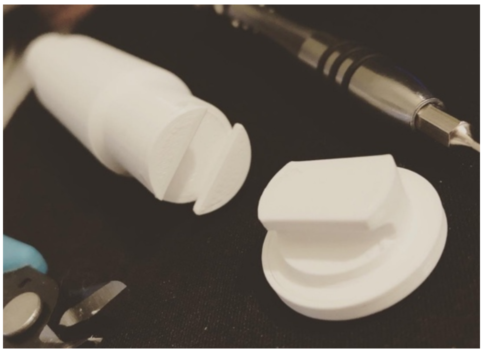

Figure 18 - Improved hub-axel connection from Loket1

Lessons learned

I have learned some lessons specifically while working on this project.

Save early, often, after each major change and label each version with a note on what has changed. This allows version control to shine by making it easier to go back in time to reflect upon one's design process. As I was attempting to reflect on the simple versus the advanced telescoping design, I wanted to see my design process. Reflecting on what was modeled and when is difficult because my saves seemed random and undocumented. I've learned to save specifically at each design change and label the save with a simple text to help my future self understand what has been accomplished.

The Future is Bright

Additive manufacturing has its strengths and weaknesses. The more I work with it the more I realize how it is such a young field that has a lot of growth opportunity ahead of it. Traditional subtractive manufacturing and construction has been around for hundreds of years and it has had those hundreds of years of collective worldwide practice to mature. Additive manufacturing has arguably been around for less than one generation and the technological capabilities already are astonishing.

Much of the advantages of additive manufacturing are only possible because of the advances in computing and software that allows for amazingly complicated calculations to create intricate CAD models and guide ever more intricate machines to microns level of precision. I am continually impressed by the possibilities of additive manufacturing.

Figure 19 – My collection grows. Loket 4 (black), 5 (grey) and 1 (white)

Figure 20 – The plastic that gave it's life to the Lok5 cause.