# MISSION PERFORMANCE OF DIFFERENT LANDING GEAR TYPES IN MEDIUM SIZED TWIN ENGINE HELICOPTERS

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## ABSTRACT

Retractable wheeled landing gears (RWLG) are standard equipment on most large helicopters above 6 tons. They offer better aerodynamics in cruise, improved passenger comfort during landing and enable taxiing compared to skids. However, they are significantly more complex, heavier and more expensive which is why skids are the norm on small to medium helicopters. This paper explores the influence of weight and aerodynamics on a medium sized helicopter using three example missions in the preliminary design software NDARC. The paper shows the steps to model the helicopter and missions in NDARC and shows the results for a reference skid gear and a reference retractable wheeled landing gear configuration. Additionally, parameter sweeps of weight and drag area of the landing gear are presented as carpet plots to show the effect of other configurations. The achievable mission range is highly dependent on landing gear weight in cases where fuel weight is limited by the MTOW. For a fixed mission range the fuel savings due to decreased aerodynamic drag of the RWLG approximately offset the higher power demand in hover and slow flight caused by the increased weight. Depending on the share of fast cruise in a mission the difference in fuel burn can range from -2% to +2%.

## NOMENCLATURE

**Symbols**

| | |
|---|---|
| $c_{d,mean}$ | Mean Profile Drag Coefficent [-] |
| $C_DS$ | Drag Area [$m^2$] |
| $C_T$ | Thrust Coefficient [-] |
| $GW$ | Gross Weight [kg] |
| $P$ | Power [W] |
| $V$ | Speed [m/s] |
| $W$ | Weight [kg] |
| $\mu$ | Advance Ratio [-] |
| $\sigma$ | Rotor Solidity [-] |

**Subscripts**

| | |
|---|---|
| 0 | Profile (Drag or Power) |
| AC | aircraft |
| br | best range |
| coll | Collective |
| i | Induced |
| pay | Payload |
| req | Required |

**Abbreviations**

| | |
|---|---|
| CAMRAD | Comprehensive Analytical Model of Rotorcraft Aerodynamics |
| GeNRoC | Genetic NDARC Rotor Calibration Tool |
| NDARC | NASA Design and Analysis of Rotorcraft |
| TUM | Technical University of Munich |
| RWLG | Retractable Wheeled Landing Gear |
| VTOL | Vertical Take-Off and Landing |

## INTRODUCTION

Skid landing gears for helicopters are the simplest and cheapest landing gear type which is why they are used on most single engine and light twin engine helicopters such as the Airbus H125 (single engine) and H145 (twin engine), shown in Fig. 1. Compared to skids wheeled landing gears offer multiple advantages. They can offer more suspension during landing which increases passenger comfort and resilience against hard landings while also providing the ability to taxi on the ground which can save fuel and decrease pilot workload. While military and utility helicopters, such as the UH60, commonly employ fixed wheeled gears, large civilian helicopters are often fitted with retractable wheeled landing gears (RWLG), as can be seen on the Airbus H170 shown in Fig. 1. Skid landing gears can account for almost a quarter of the overall parasite drag of a helciopter (Ref. 1) with fixed wheeled gears having even worse aerodynamics (Ref. 2). RWLG therefore offer great drag reduction potential for helicopters. They do however come with higher complexity and therefore cost, maintenance and especially weight. Choosing the best gear configuration for a helicopter is therefore dependent on the aircraft, its mission and customer preferences.

This paper investigates the performance of skids and RWLG for a light to medium twin engine helicopter similar to the H145 but heavier. The investigations are conducted for three example mission types. First the modeling environment used to model the aircraft and simulate the missions is presented. Then the aircraft model

Figure 1: Picture of the Airbus H145 helicopter with skid landing gear (Ref. 3) and the Airbus H175 helicopter with retractable wheeled landing gear (Ref. 4)

is described and the investigated missions are defined. Lastly, the results are shown, discussed and the conclusions are presented.

## MODELING ENVIRONMENT

Modeling of the missions is conducted in the preliminary design software NASA Design and Analysis of Rotorcraft (NDARC). The software uses parametric aircraft models and can be used to either analyze the performance of existing configurations in specific flight states and missions or to size new configurations for a design mission. For this paper it is used for analysis. For the analysis presented in the results a large number of missions are simulated. To automate this process the NDARC-Python interface RCOtools (Ref. 5) is employed in combination with the analysis and optimization framework OpenMDAO (Ref. 6). Fig 2 shows the resulting software framework.

An integral stage in the development of an NDARC

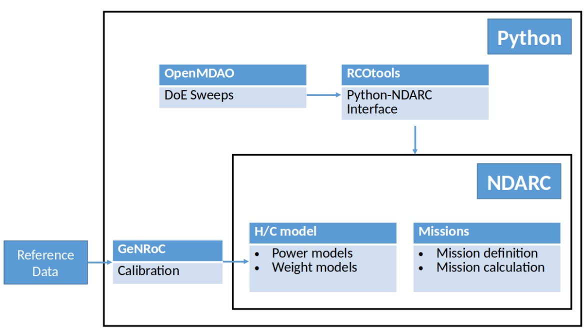



Figure 2: Modeling environment for mission performance calculations

model is the rotor performance model. NDARC models rotor power as the sum of induced and profile power. The formulation of the induced power model involves an extended version of momentum theory, while the profile power calculation is based on the mean blade section drag coefficient. To account for rotor characteristics beyond the scope of classical momentum theory and constant mean section drag, surrogate models are introduced to extend these models.

However, the surrogate models necessitate precise calibration with specific parameters to accurately represent real-world rotor systems. Calibration data is derived from higher fidelity models, such as comprehensive analyses (e.g., CAMRAD II or DYMORE). The standard process for calibration is carried out through a laborious process utilizing an Excel spreadsheet, where results from defined comprehensive analysis sweeps are input, and parameters are manually tuned through plot comparisons. The time-intensive nature of this calibration procedure poses a significant hindrance in the creation of a novel NDARC aircraft model. To expedite and streamline this process, and enhance accessibility for new users, a novel calibration tool named *GeNRoC* (Genetic NDARC Rotor Calibration) has been developed and integrated into the workflow shown in Fig. 2. (Ref. 7)

Fig. 3 depicts the architecture of the GeNRoC tool.

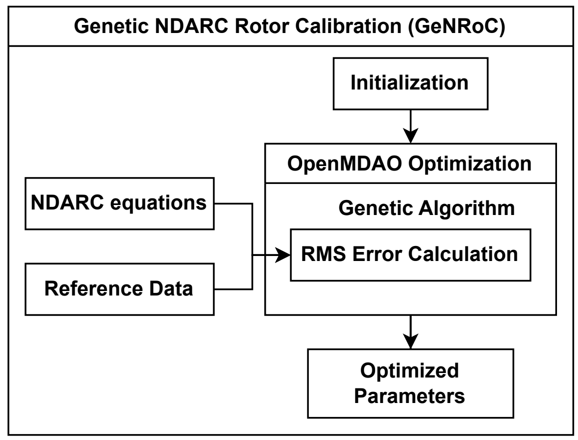



Figure 3: Architecture of the Genetic NDARC Rotor Calibration (GeNRoC) tool

The tool utilizes a genetic algorithm provided by OpenMDAO (Ref. 8) to minimize the error between the reference data and the output of the calibrated model since the code of the surrogate models employ many `if` and `abs()` statements which lead to convergence problems with classical gradient based optimization algorithms. The tool was validated using a reference NDARC model and CAMRAD II data for the UH-60A (Refs. 7, 9).

## HELICOPTER MODEL

The investigated aircraft is a medium sized helicopter with a similar rotor system to the H145, specifically BK117-D3, depicted in Fig. 4. The aircraft model used for the investigation is based on reference data from a detailed aircraft model of the BK117-D3 provided by Airbus. A parametric NDARC model was created using the data from the detailed model. Lift and drag derivatives of fuselage and stabilizers were derived from airfoil/fuselage polars in the reference model. For the rotor performance sweeps of gross weight, flight speed and altitude were conducted with the reference

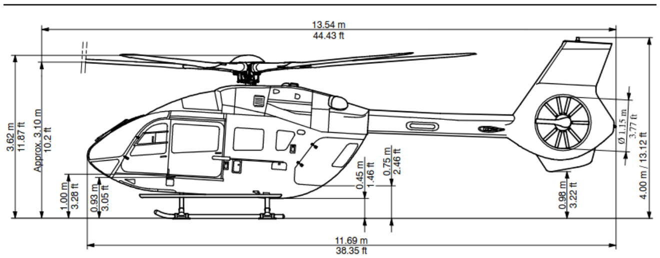



Figure 4: Dimensions of the BK117-D3 helicopter (Ref. 10)

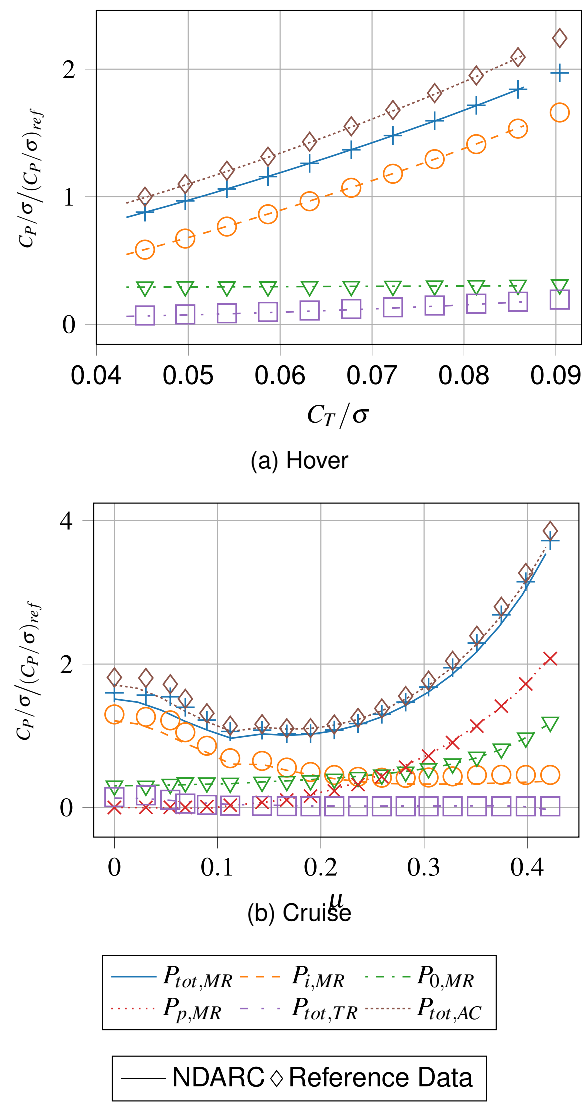
model. The calculated power values were then used as reference data to generate a NDARC rotor performance model using the GeNRoC tool.

Figure 5 shows the results of the calibration of the NDARC submodels conducted using the GeNRoC tool. Normalized performance data calculated with NDARC and the reference model are shown for a hover case and a forward flight case. The data shows very good agreement between the results for hover flight. All power components are nearly identical. In fast forward flight ($\mu > 0.15$), there is also very good agreement between all power components. In slow flight ($\mu < 0.15$), significant discrepancies are visible between the NDARC and reference model results. However, since the missions simulate either hover or at least speed for maximum endurance ($V_{BE}$ corresponds to minimum of the curve), the slow flight states are not relevant here and can thus be neglected.

For the calculations of fuel consumption and range, an engine model is required in addition to the performance model. No detailed engine model was available for the Arriel 2E used in the H145. Therefore, a generic engine model with similar performance to the H145 from the NDARC database was used for this purpose. The model was adapted to the maximum continuous power (MCP) and the specific fuel consumption (SFC) at rated power of the H145. This data was taken from the Airbus H145 technical specification provided by Airbus.

The H145 model was set up parametrically and unitless so that all values such as component weight, absolute lift, drag area and the rotor performance model appropriately scale with the MTOW of the aircraft. This way the model of the medium sized helicopter, which has a similar rotor system to the BK117-D3, was derived by changing the MTOW of the H145 model.

Fig. 6 displays the relation between landing gear drag area and MTOW of the helicopters as a linear correlation. From the data the skid landing gear drag area for larger helicopters could be derived. However, this data is from 1975 which means that advances in aerodynamic modeling and construction of the skid gears are not accounted for. While the BK117-D3 does not employ aerodynamically faired skids, which are also shown in Fig. 6, Fig 7 shows that the frontal area of the H145




(a) Hover

(b) Cruise

Figure 5: Normalized power data calculated with H145 reference model and the calibrated NDARC model in hover and forward flight. Shown are the total power of the helicopter (AC), main rotor (MR), and tail rotor (TR), as well as induced power ($i$), profile power ($0$), and parasitic power ($p$) of the main rotor.

skids is similar to that of the BO105. The drag area of the BK117-D3 skids was therefore assumed to be similar to that of the BO105. For the investigated medium sized helicopter this value was then scaled according to the MTOW.

Depending on the RWLG configuration the wheels might not be retracted into the fuselage and covered fully, as can be seen in Fig. 1. For the new medium sized helicopter it was estimated that wheels will be retracted half-way so that the wheel hub aligns with the fuselage. Drag of the half-way retracted wheels can be estimated from the frontal area of the wheels according

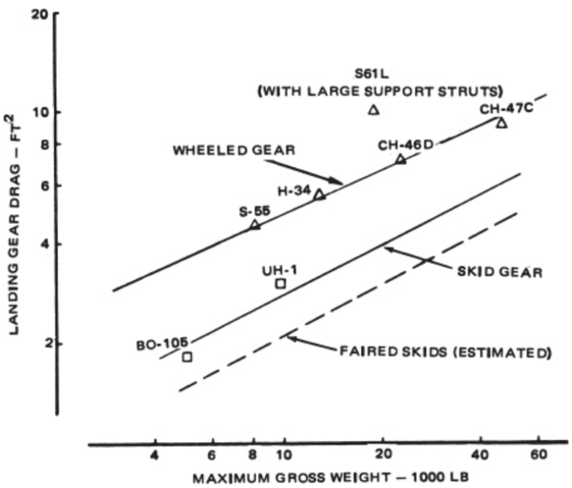



Figure 6: Landing gear drag area depending on MTOW according to Keys 1975 (Ref. 2)

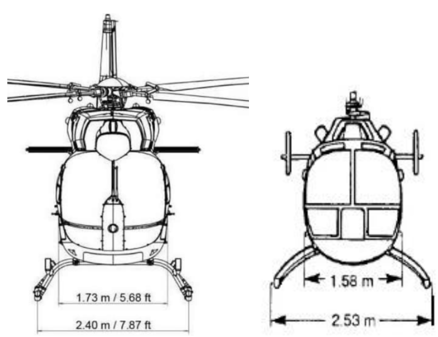



Figure 7: Comparison of BO105 (Ref. 11) and H145 skid dimensions (Ref. 10)

to HOERNER (Ref. 12).

$$\frac{D}{q} = A_{ref} \cdot C_D \tag{1}$$

$$A_{ref} = n_{wheels} \cdot 2R \cdot b \tag{2}$$

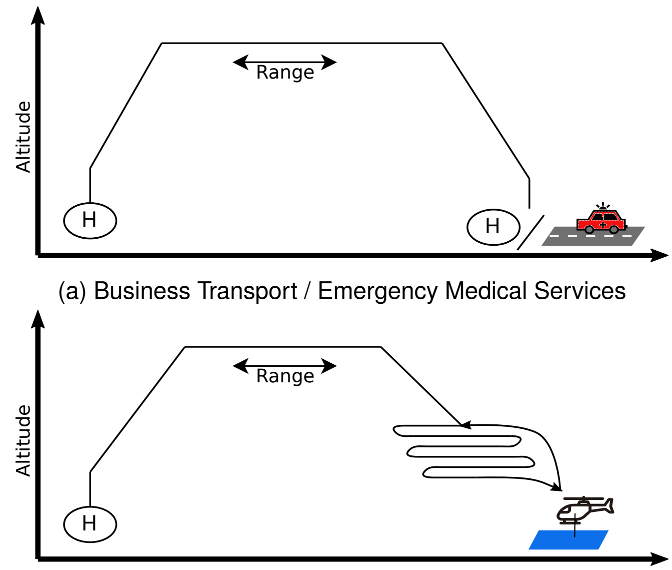
To integrate the rear wheel gears onto a helicopter of this size class, external sponsons will likely be necessary that are not needed for the attachment for skid attachment. Since exact drag of this will be highly dependent on the final design a 100% margin is used to approximate the drag influence of the sponsons.
The weight for the skid gear is based on the weight of the H145 skid gear provided by Airbus. The RWLG weight is a result of design investigations within the HelLa project. The resulting reference skid and RWLG configurations are shown in Tab. 1.

## MISSION DEFINITION

The investigations were conducted for 11 different missions during the project that these results were created in. Since many of these investigations showed similar results the following will focus on 3 representative missions. The first mission is a Business Transport, depicted in Fig. 8a, from heliport to heliport plus the return trip. Take-off is modeled as a short hover after which the helicopter climbs to cruise altitude. The cruise segment and descent are flown at best range speed. Landing is again modeled as a short hover. The helicopter is equipped with normal passenger seats and fully loaded with passengers plus one pilot. The second mission, also shown in Fig. 8a, is the Emergency Medical Services (EMS) mission in which the helicopter flies to an accident at fast cruise speed from a base or hospital, takes on a patient at the accident site and flies back to the hospital. The helicopter is fitted with appropriate medical equipment. At take-off the pilot plus a doctor and a medical assistant are aboard the helicopter. The last mission is a maritime Search-and-Rescue (SAR) mission, shown in Fig. 8b. The helicopter flies from a base to a search area at fast cruise speed. A search pattern at best endurance speed is flown after which the rescue operation is conducted in hover, it takes on three rescued persons and returns to base afterwards. The helicopter is equipped with winch, appropriate avionics for SAR operations and internal equipment for rescue operations. At take-off two pilots, a winch operator and a rescuer are aboard. The equipment, crew and payload weights mean that the business mission has the highest weight without fuel at the beginning of the mission while the EMS helicopter is lightest before fuel.

| | Skids | Retractable Wheel LG |
|---|---|---|
| Weight | 1 | 3.5 |
| $C_D S$ | 1 | 0.35 |

Table 1: Weight and drag area of a reference skid and a retractable wheeled landing gear configuration, normalized to the skid gear values




(a) Business Transport / Emergency Medical Services



(b) Search-and-Rescue

Figure 8: Visual representation of mission profiles

All missions account for a 30 minute cruise reserve at best endurance speed and a 10% fuel margin overall.

## RESULTS & DISCUSSION

Depending on operator preferences and their specific missions the achievable range and/or the fuel consumption for these missions can both be important factors when acquiring a new helicopter. Therefore, both the maximum achievable range and the burned fuel at a fixed mission range were investigated.

### Achievable Range

To evaluate the achievable range with a given landing gear configuration for a given mission, the mission is simulated in NDARC considering the configurations shown in Tab. 1. The total weight at take-off is accounts for the aforementioned equipment and payload weights, the landing gear weight and the fuel weight. Fuel weight is either calculated from the remaining weight margin to MTOW or the fuel tank capacity provided by Airbus (Eq. 3).

$$W_{fuel} = min \begin{cases} W_{fuel,capacity} \\ MTOW - W_{empty} - W_{pay+crew} - W_{equip} \end{cases} \quad (3)$$

Tab. 2 shows the difference in achievable range between the RWLG and the skid gear equipped helicopter with the skid configuration being the reference. It shows that for the corporate transport mission a significant drop in range occurs while EMS and SAR missions are much less affected. This significant decrease for the corporate transport mission is caused by the much higher payload weight for this mission. The higher payload means that even with the skid configuration the tank capacity cannot be fully utilized. Therefore, the extra weight for the RWLG compared to skids directly reduces the maximum fuel weight that can be carried and thereby reduces the achievable range.

The EMS mission can be flown with full fuel tank with both configurations. In this case the improved aerodynamics of the RWLG offset the increased weight and lead to a slight increase in achievable range. The Search-and Rescue mission lies in-between. Here the mission can be flown with a full tank with the skid gear and slightly reduced fuel load with the RWLG. Since these trends rely heavily on the exact weight of the final landing gear configuration which might vary from the modeled values, parameter sweeps were conducted. Landing gear weight and drag area were varied to cover a all possible landing gear configurations. The results are presented as carpet plots, like e.g. Fig. 9. The remaining plots can be found in the appendix.

| Mission | Δ RWLG |
| --- | --- |
| Corporate Transport | $-20\%$ |
| EMS | $+1\%$ |
| SAR | $-4\%$ |

Table 2: Effect of retractable wheel gear on achievable range for example missions compared to skid gear

Fig. 10 shows the results of the parameter sweep for the corporate transport mission as a carpet plot. The steep lines of the weight axis show that due to the high payload weight the achievable range is significantly more dependent on the landing gear weight compared to aerodynamic drag area. The reference configurations compared in Tab. 2 are represented as dots and show the high discrepencany in achievable range.

In comparison the same plot for the EMS mission shows that here drag has a slightly higher influence on range compared to weight in the investigated range. At the assumed drag area reduction to 35% of the skid gear even a further 25% increase in RWLG weight would not result in a decreased range. Assuming the RWLG could be constructed with fully retracting wheels and without sponsons the carpet plot shows that a range increase of approximately 2% would result. While this is not a large increase in range it could make a difference especially for emergency medical missions.

Finally, the carpet plot for the SAR mission shows both trends in one plot. As the SAR mission has a medium combined payload and equipment weight, the mission can still be flown with a full tank with the reference skid gear weight. However, at 200% of the skid weight the MTOW is reached and any further increase in landing gear weight reduces the fuel that can be carried and leads to a significant decrease in range.

### Burned Fuel at Fixed Range

To investigate the effect on fuel efficiency the missions are simulated at a fixed range. The range is chosen so that all evaluated pairs in the parameter sweep can be flown without exceeding the fuel capacity. Therefore, the EMS mission is simulated with the highest range while the corporate transport mission has a significantly reduced range. The SAR mission has the lowest cruise distance since it also incorporates the fixed search pattern and hover time. The fuel at take-off is calculated by NDARC as the fuel needed to fly the mission including the reserve (Eq. 4).

$$W_{fuel} = W_{fuel,burned} + W_{fuel,reserve} \quad (4)$$

Tab. 3 shows the results for the reference configurations. Now that the carried fuel weight is not a factor both configurations the results for all missions mirror those of the range investigation for the EMS mission. For the reference configurations fuel consumption is

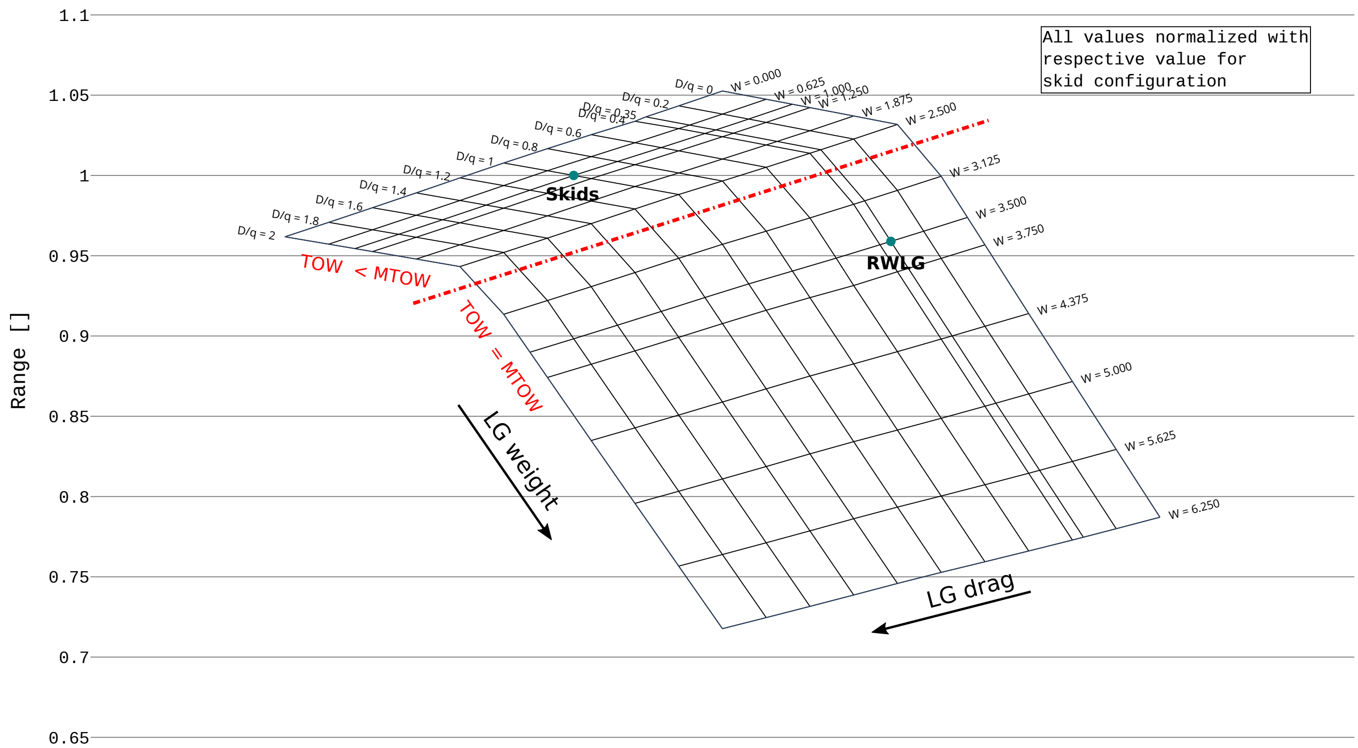



Figure 9: SAR mission: Impact of of different landing gear weights and drag area values on achievable range.

nearly the same in all cases. Only for the EMS mission a 1% fuel saving can be found.

As for the range investigation parameter sweeps

| Mission | Δ RWLG |
|---|---|
| Corporate Transport | $0\%$ |
| EMS prim. | $-1\%$ |
| SAR | $0\%$ |

Table 3: Effect of retractable wheel gear on burned fuel for example missions at fixed range, compared to skid gear

were conducted. These sweeps emphasize the slight advantage that the RWLG brings to the EMS mission as it is the mission which profits the most, as can be seen in Fig. 13. The reason for this is the high cruise percentage of the simulated mission compared to the other missions. While the corporate transport mission, shown in Fig 12, has the same general mission profile the cruise distance is shorter while take-off and climb segments are fixed. Therefore, the influence of the improved aerodynamics in cruise is lessened and for the reference configurations only exactly offsets the higher power demand in hover and climb due to increased weight. The SAR mission, shown in Fig 14, profits even less from the lower drag of the RWLG due to its higher hover share and search pattern which is flown at the slower best endurance speed.

## CONCLUSIONS

For this investigation the following steps were conducted:

1. A calibrated model of the H145 helicopter was created using the GeNRoC calibration tool.
2. Several missions were simulated using a software environment based on NDARC embedded in a Python framework.
3. Simulations were conducted for a reference skid gear and a retractable wheeled landing gear (RWLG) with half retracting wheels and sponsons.
4. Additional parameter sweeps were conducted to show results for any possible input combination of drag and weight so that the calculations are valid even if the final design of the landing gear does not have the modeled drag area and weight.

The most important conclusions of this paper are as follows:

1. Achievable mission range is highly dependent on landing gear weight in cases where fuel weight is limited by the MTOW. This is influenced by payload and mission equipment.
2. If MTOW is not the limiting fuel load small increases in range can be found for missions that consist mostly of cruise flight.
3. For a fixed mission range the improved aerodynamic drag of the RWLG offsets the weight increase. For missions with high cruise share the

RWLG does offer slight advantages, although these are within 1% for the investigated reference gear configurations.

4. A fully retractable landing gear without sponsons would further shift the results in favor of the RWLG.

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## APPENDIX

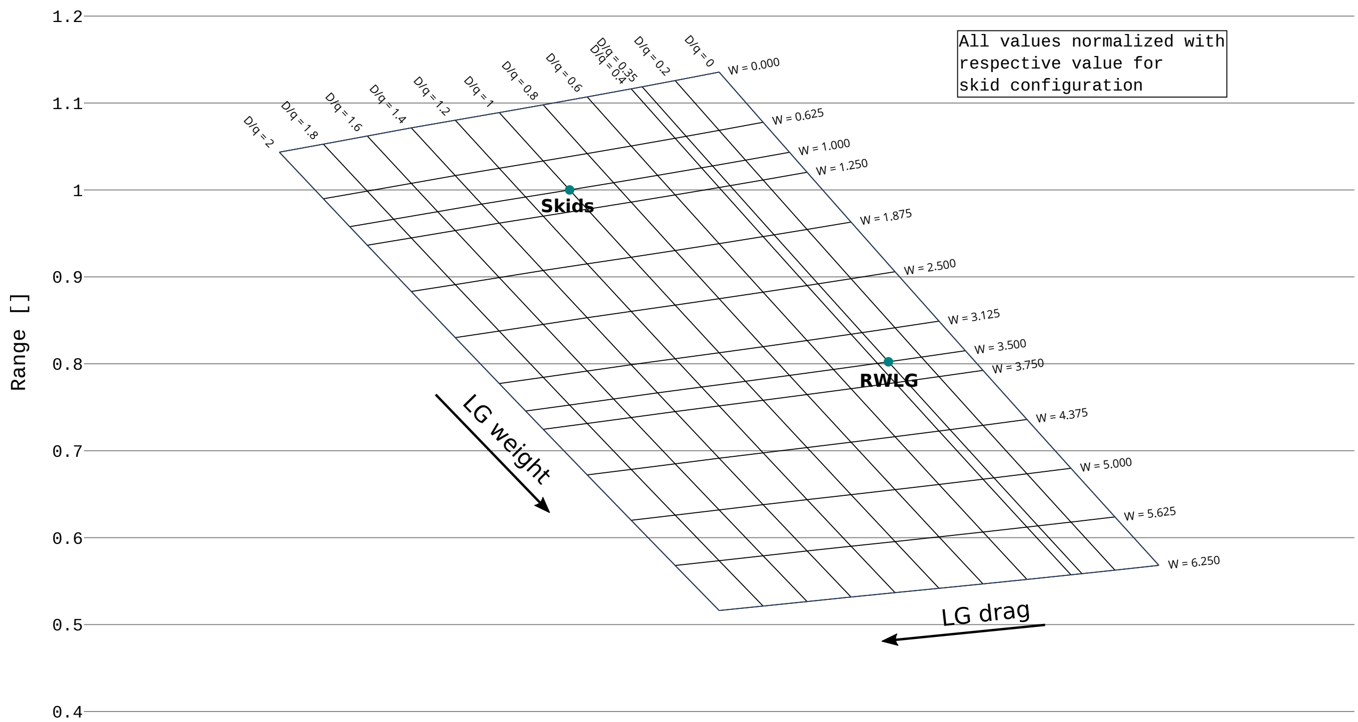


Figure 10: Corporate Transport Mission: Impact of of different landing gear weights and drag area values on achievable range.

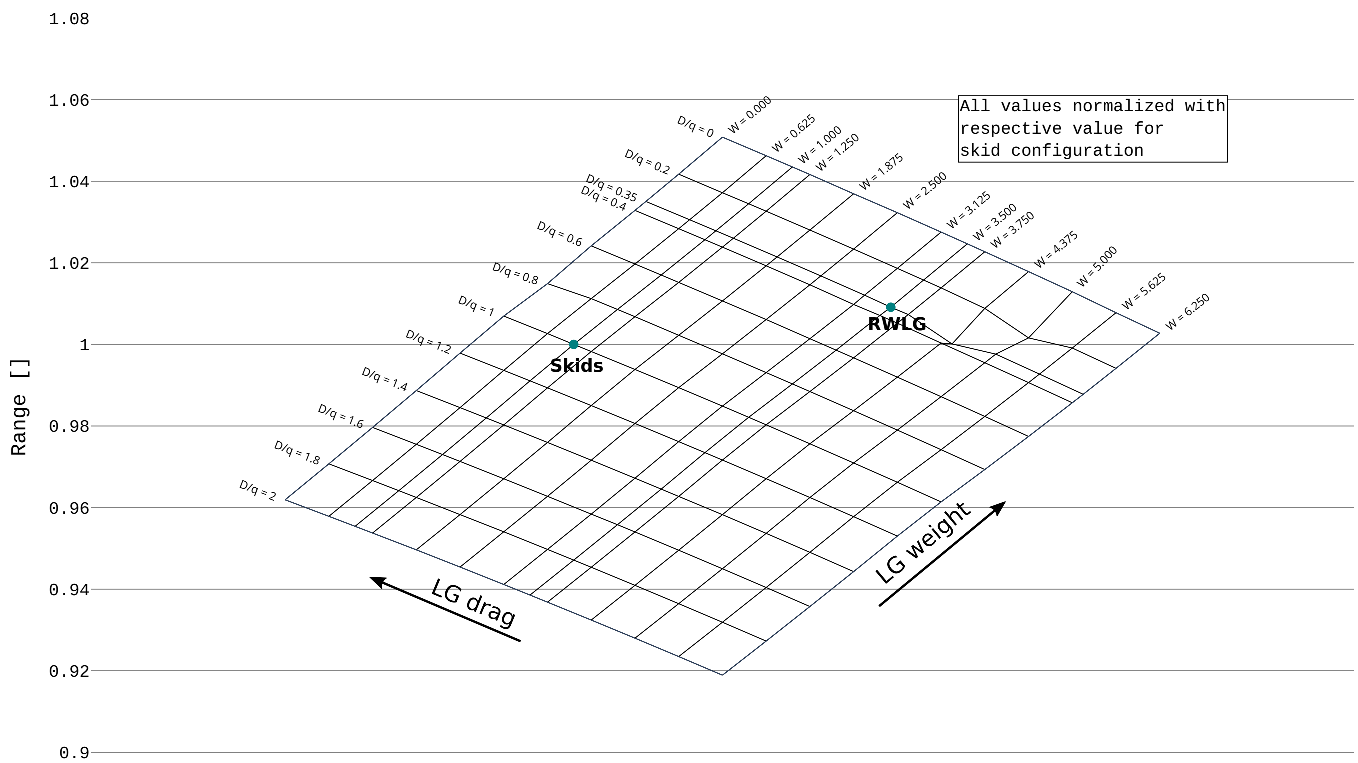


Figure 11: EMS Mission: Impact of of different landing gear weights and drag area values on achievable range.

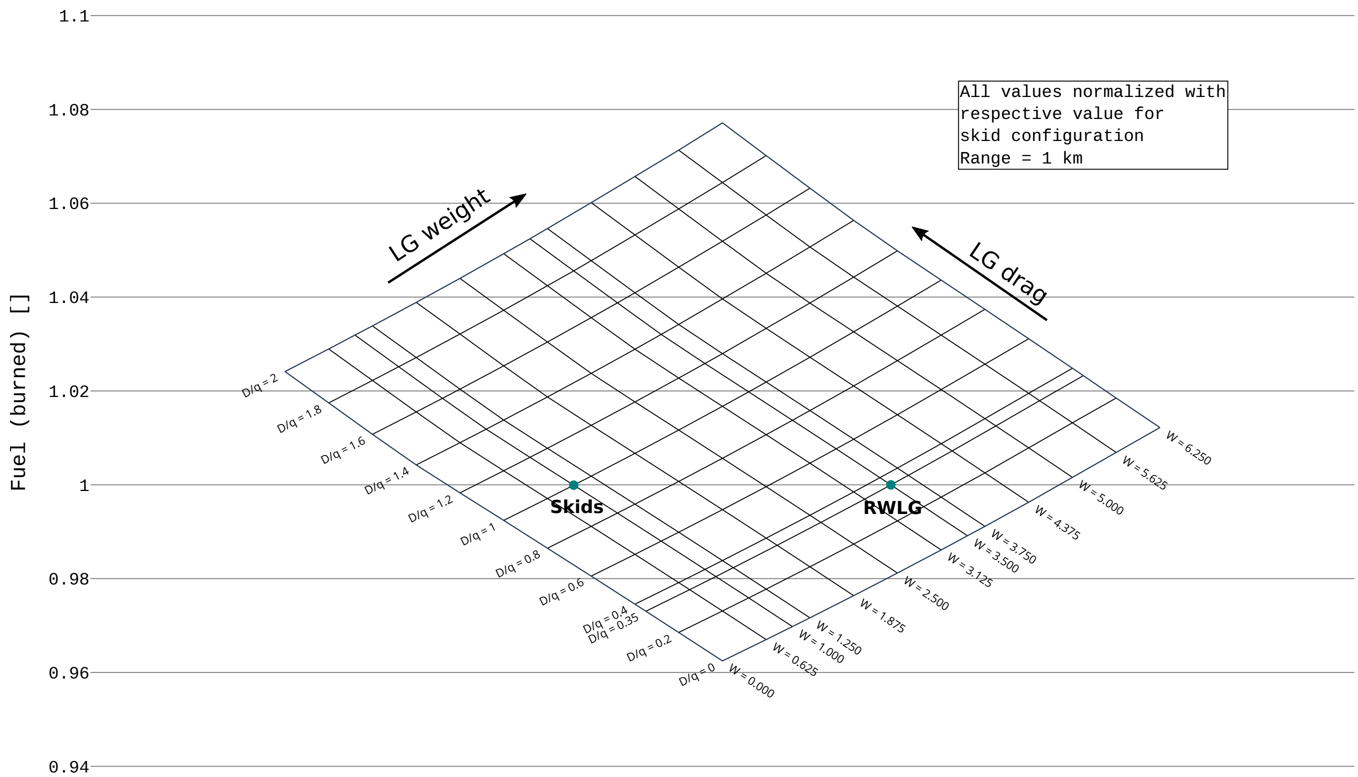


Figure 12: Corporate Transport Mission: Impact of of different landing gear weights and drag area values on the burned fuel at fixed range.

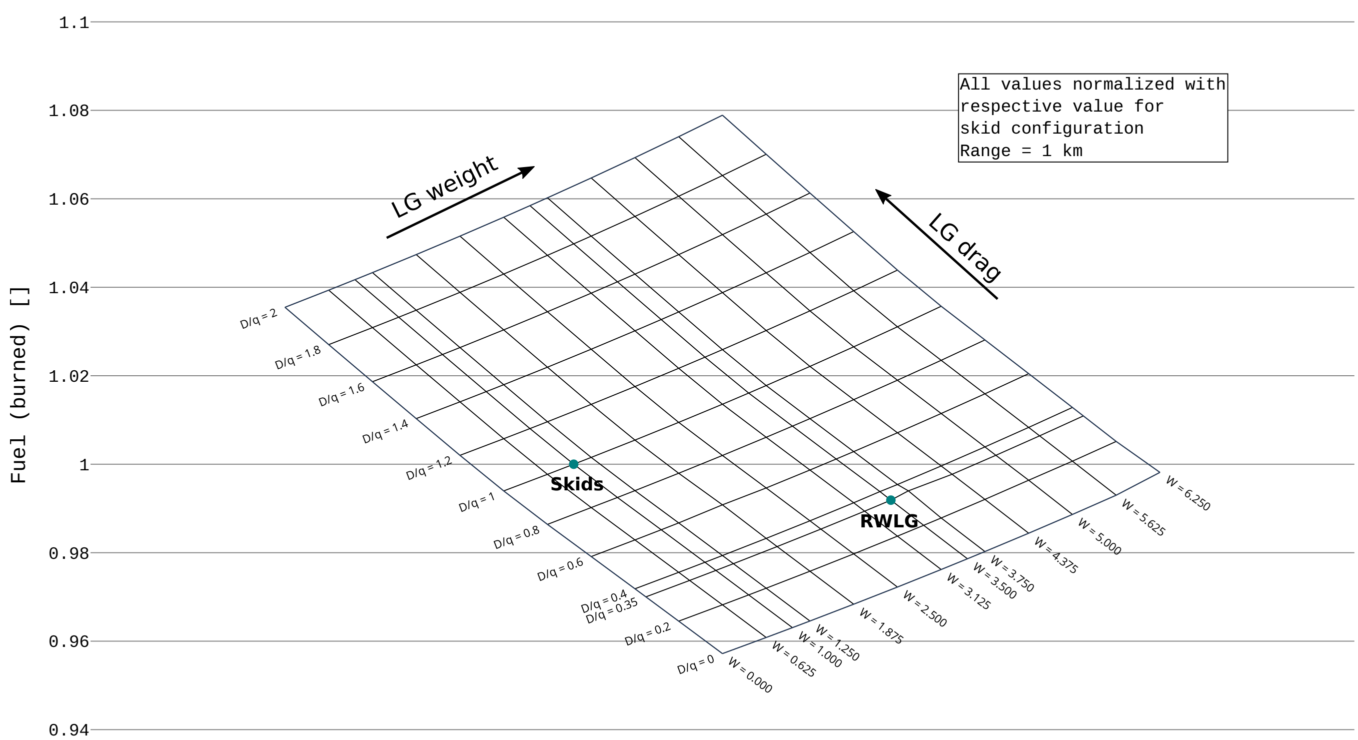


Figure 13: EMS Mission: Impact of of different landing gear weights and drag area values on the burned fuel at fixed range.

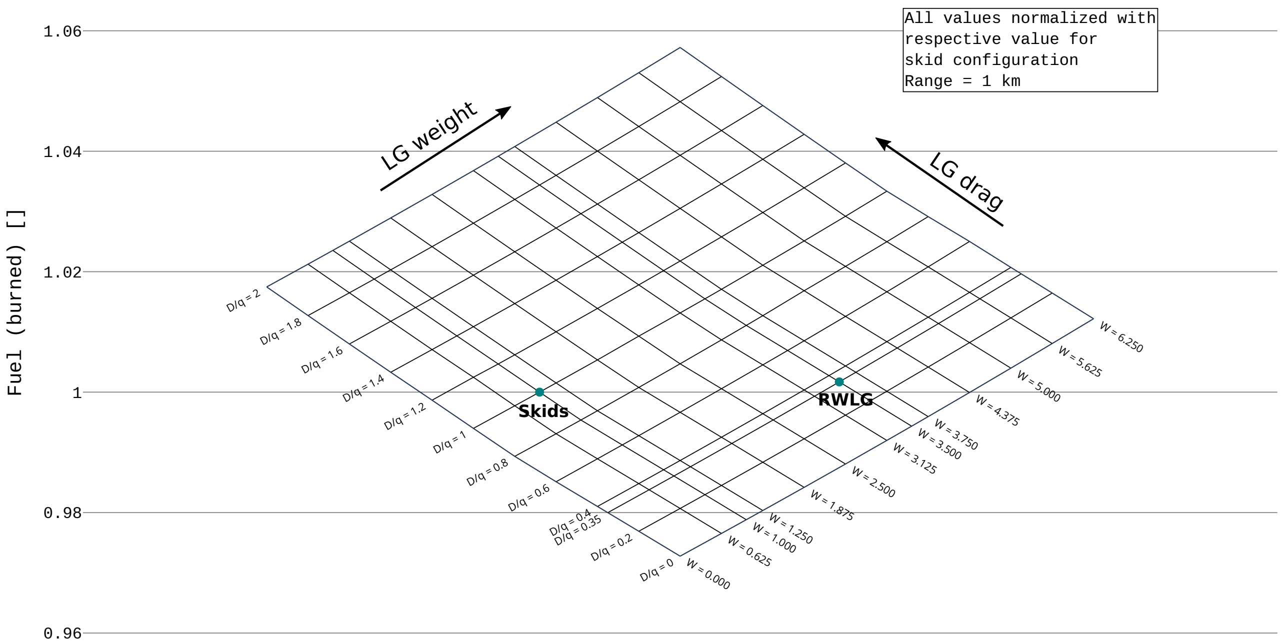


Figure 14: SAR Mission: Impact of of different landing gear weights and drag area values on the burned fuel at fixed range.