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AIRCRAFT DOCKING GUIDANCE SYSTEM TO THE GATE USING FUZZY LOGIC

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Abstract

The article presents the concept of automated final process of aircraft taxiing to the gate at the terminal. On the basis of an analysis of the possibilities of aircraft taxiing in civil airports, the authors attempted at optimizing this process. The main objective of the project is to reduce the taxiing time, consequently reducing fuel consumption as well as the rotation time. As a result of the work, the authors designed a controller based on fuzzy logic, which, depending on the initial parameters, calculates the set values for the execution system of aircraft control in the horizontal plane and for the taxi speed. The controller receives two input signals, which determine two output signals. The designed controller allows comprehensive and fully automated aircraft steering. The project relies on data with regard to the apron class D, suited to handle aircraft with a wingspan of up to 52 m and the characteristics of a Boeing 767-200 in speed taxiing and the maximum turn of the nose gear. The measurements of the apron have been adopted in accordance with international regulations in the ICAO DOC 9157 "Aerodrome Design Manual". The maximum deviation of the nose gear from the centre line was assumed 2.5 m in each direction and a safe distance behind the immobile aircraft equal to 25 m. The length of the Boeing aircraft 767-200 is below 48 m, therefore the input boundary parameters are equal to +/- 2.5 m from the centre line and 80 m from the designated aircraft stand (nose gear). The article presents the project of the controller and its optimization. The authors simulated the controller operation in the package MATLAB "Simulink". The article ends with data analysis and final conclusions.

Keywords: *fuzzy logic, fuzzy expert system, aircraft taxiing, aircraft steering*

1. Introduction

On the basis of an analysis of the possibilities of aircraft taxiing in civil airports, and research from the last decade [2, 8, 9], the authors attempted at optimizing this process. The article presents the concept of an automated final process of aircraft taxiing to the gate at the terminal. The main objective of the project is to reduce the taxiing time, consequently reducing fuel consumption as well as the rotation time. As a result of the work, the authors will design a controller based on fuzzy logic [1, 5, 7], which, depending on the initial parameters, will be capable of calculating the set values for the execution system of aircraft control in the horizontal plane and for the taxi speed.

2. Project assumptions

The project relies on data with regard to the apron class D, suited to handle aircraft with a wingspan of up to 52 m and the characteristics of a Boeing 767-200 within taxi speed and the maximum turn of the nose gear.

The dimensions of the apron are specified by the international regulations of ICAO DOC 9157 "Aerodrome Design Manual". They describe the maximum deviation of the nose gear from the centre line, which is equal to 2.5 m in each direction; the safe distance behind the stationary aircraft must be at least 25 m. The length of the Boeing 767-200 aircraft is below 48 m, thus the input boundary parameters will be +/- 2.5 m from the centre line and 80 m from the final parking stand (nose gear) [4].

The parameters describing the Boeing 767-200 are the wheel turn +/- 60º and the taxi speed to the gate, specified as less than 18 km/h. For the needs of the design, the ranges of boundary values are between 0 and 18 km/h, whereas the wheel turn was restricted to +/- 45º by the constructor. Since one of the input parameters is described as a deviation to the left or to the right from the centre line, its control planes will be symmetrical to one axis; therefore, the tests may be carried out only for the mid-range.

2.1. Description of the controller

At the input of the designed fuzzy logic controller (Fig. 1), two input signals specify the distance from the line of the parking stand (DistanceToGate) and the distance of the nose gear to the centre line (DistanceToCentre). At the output, two output parameters will be specified, indicating the aircraft speed (Speed) and turn of the nose gear (WheelTurn), depending upon the value of the input parameters. The centre of gravity was assumed for the defuzzification method. The resulting defuzzified value was determined by means of the surface centre of gravity coordinate under the resulting curve of the membership function. The advantage of this method is the fact that all active rules are involved in the defuzzification process, thus rendering it objective. The disadvantage is a large computational effort needed to achieve results.

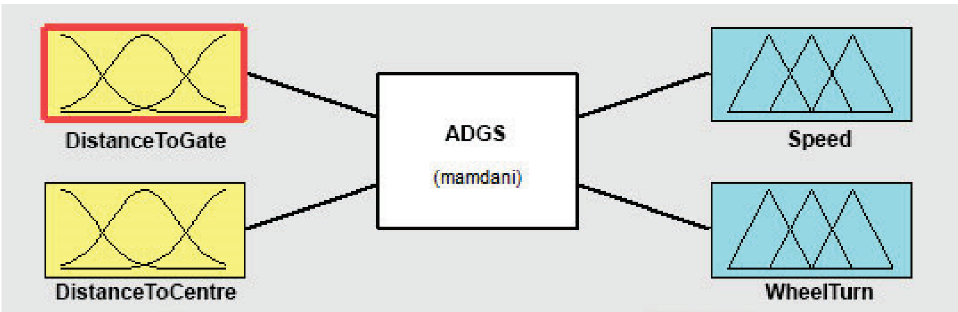


Fig. 1 Fuzzy logic controller scheme with inputs and outputs

The first of the input signals describes the distance from the parking stand within the range of 0-80 m. The signal was described by 6 membership functions. It is shown in Tab. 1.

The second input signal determines the position of the aircraft nose gear against the centre line of taxiing in the range of -2.5 up to 2.5 (m), which means deviation to the left or right, respectively. The signal was described by 8 membership functions. It is shown in Tab. 1.

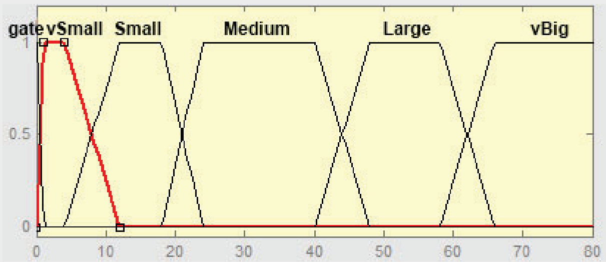
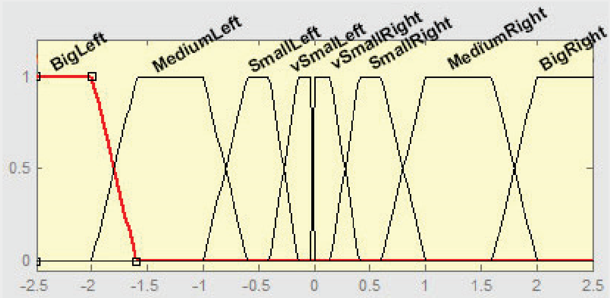
The output signals have been successively described as follows:

– speed expressed in kilometres per hour in the range of 0 and 18 km/h, described by 5 membership functions,
– wheel turn in the range of +/- 45º, described by 7 membership functions (Tab. 2).

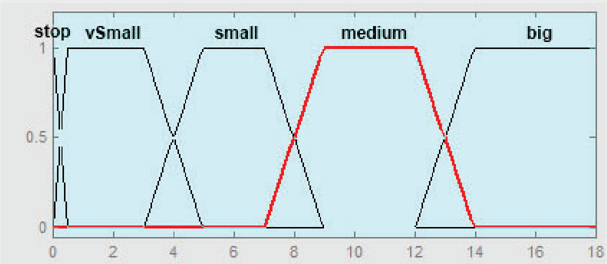
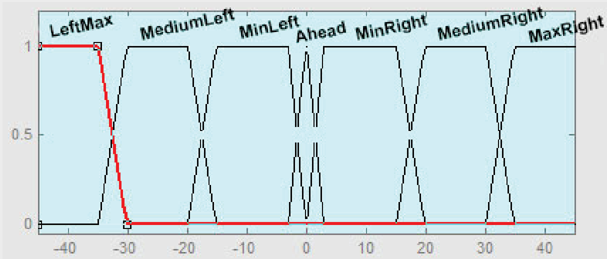
2.2. The base of principles

In order to programme the controller, it is necessary to establish the principles it will be using. This is done by “teaching” the programme how to calculate, by specifying the ranges of the membership function output parameters, depending on all possible combinations of input parameters. The number of these combinations depends on the amount of membership functions in particular input signals [3, 6]. The designed controller has 6 and 8 membership functions, in the input signals, which makes 48 deduction principles.

Tab. 1. Membership functions and their ranges for input signals

Input signal	Membership functions	
DistanceToGate [m]	*gate* [0 0 1] *vSmall* [0 1 4 12] *Small* [4 12 18 24] *Medium* [18 24 40 48] *Large* [40 48 58 66] *vBig* [58 66 80 80]	
DistanceToCentre [m]	*BigLeft* [-2.5 -2.5 -2 -1.6] *MediumLeft* [-2 -1.6 -1 -0.6] *SmallLeft* [-1 -0.6 -0.4 -0.15] *vSmallLeft* [-0.4 -0.15 -0.008 0] *vSmallRight* [0 0.008 0.15 0.4] *SmallRight* [0.15 0.4 0.6 1] *MediumRight* [0.6 1 1.6 2] *BigRight* [1.6 2 2.5 2.5]	

Tab. 2. Membership functions and their ranges for output signals

Output signal	Membership functions	
Speed [km/h]	*stop* [0 0 1.3] *vSmall* [0 1.3 8 10.6] *small* [8 10.6 16 18.6] *medium* [16 18.6 26.6 32] *big* [26.6 32 40 40]	
WheelTurn [deg]	*LeftMax* [-45 -45 -35 -30] *MediumLeft* [-35 -30 -20 -15] *MinLeft* [-20 -15 -3 0] *Ahead* [-3 0 -0.008 3] *MinRight* [0 3 15 20] *MediumRight* [15 20 30 35] *MaxRight* [30 35 45 45]	

3. Analysis of operation

The preliminary analysis of the controller's operation was based on an observation and a careful analysis of the obtained control planes. The authors evaluated the value changes along the particular axes and their mutual relationships.

After the analysis, the authors came to a conclusion that the controller works properly, in accordance with the assumptions made, however, it is necessary to make optimization to obtain more fluid transitions between successive ranges. As seen in Fig. 2, the speed changes are quite rapid on small distances, which are in fact connected with aircraft "jerkiness". In addition, the lateral ranges, at a large deviation from the centre line, are identical almost in the entire distance range to the gate (horizontal plane fragments), which corresponds to maintaining a constant speed along a certain distance section. However, the assumption is to smoothly slow down the aircraft as it approaches the parking stand. In order to reduce the observed irregularities, the authors decided to edit the ranges of membership functions as well as increasing fuzziness between them.

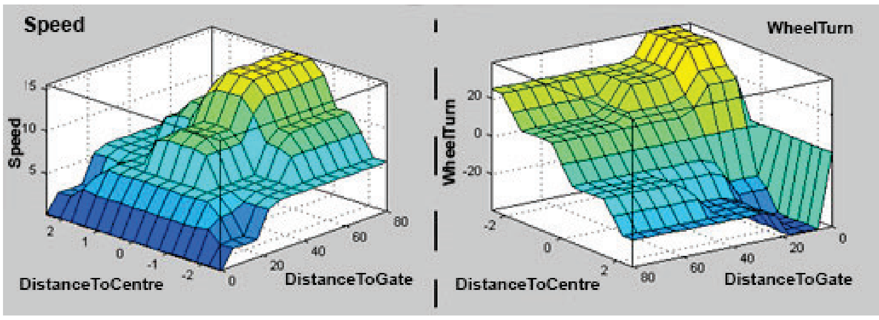


Fig. 2. Control planes of output parameters from input parameters

In case of the output signal WheelTurn, the controller works in accordance with the assumptions made, however, to make the control plane more realistic, a decision was made to change certain deduction principles. The initial concept was based on the use of a small wheel turn at a large distance from the parking stand, since the aircraft was to maintain high speed, which might excessively rock the whole construction, at a large turn. New concepts assume an introduction of larger dependency between the wheel turn and the distance as well as speed in order to faster capture the centre line and eliminate errors at as short a distance as possible.

Besides, in order to confirm the assumptions resulting from the analysis of control planes, the authors checked the controller operation on 20 test samples for the measurement points:

– on the axis related to the distance to the centre at [0 0.75 1.4 2] [m],
– on the axis related to the distance to the parking stand at [7 25 43 80] [m].

The results are shown in Tab. 7.

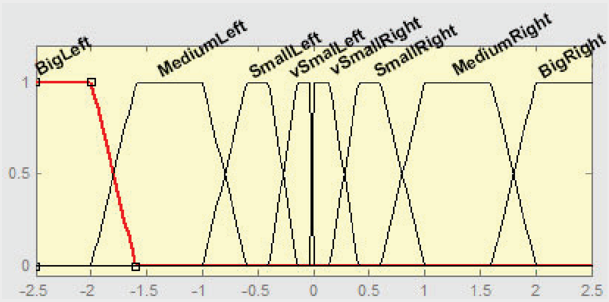
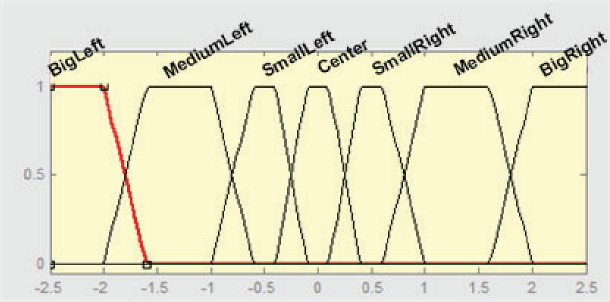
4. Optimization

In the first stage of optimization, the membership functions were modified in one input and one output parameter. On the input signal "DistancetoCentre", two centre trapezoid functions, which were the closest to the zero value, were changed for one function, also trapezoid. In this way, the computed output parameters receive a smooth transition through the zero value. Removal of one of the functions is connected with a modification of the deduction principles, particularly a change in their number. Now the first signal still has 6 functions, whereas the second has 7 functions (1 less), which makes 42 rules instead of the previous 48.

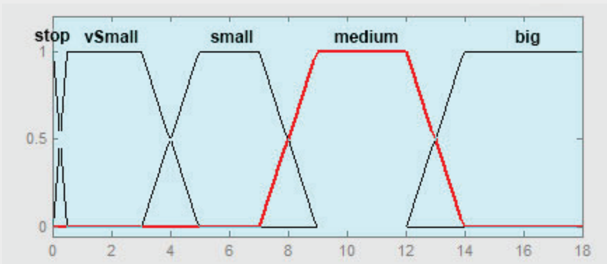
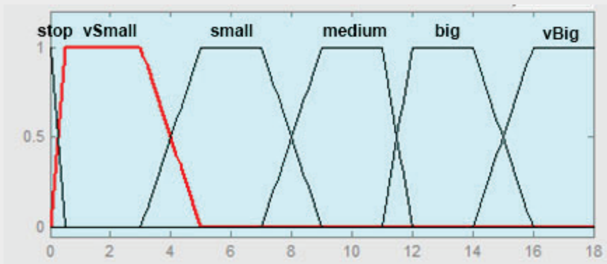
Another change at this stage was the addition of one function (vBig) to the output signal "Speed". After this operation, it was necessary to change certain deduction principles due to greater possibilities of describing the output parameter. Moreover, the horizontal ranges of membership functions also decreased. In addition, the fuzziness of the data was reduced. The changes are depicted in Tab. 3 and 4.

The first stage of the optimization was as expected. The addition of one speed range resulted in reducing peak values at the expense of a smoother transition between the maximum values (approximately 16-17 km/h), and indirect ones (approximately 12-13 km/h). Owing to such an approach, the speed of the taxiing aircraft will decrease more smoothly when nearing the parking stand. In addition, changing the deduction principles also affected the lateral speed ranges at a large distance to the centre line, so that the aircraft will decrease the speed less rapidly, when deviating from the set taxiing route. At the same time, it will faster correct the deviation. The step in-between 30 and 50 metres from the parking stand was removed. There is now a smooth transition to the full extent of the deviation from the centre line (Fig. 3).

Tab. 3. Change in membership function of the parameter "DistanceToCentre"

Before optimization	After optimization
	

Tab. 4. Addition of membership function vBig

Before optimization	After optimization
	

Changing the deduction principles had the greatest impact on the control plane of the nose gear (Fig. 3). Owing to the first stage of optimization, it was possible to change the course on the particular axes. It is worth noting that it is still symmetrical to the characteristic hollow in the vicinity of 60 m from the gate. This is a desired result, being consistent with the assumptions.

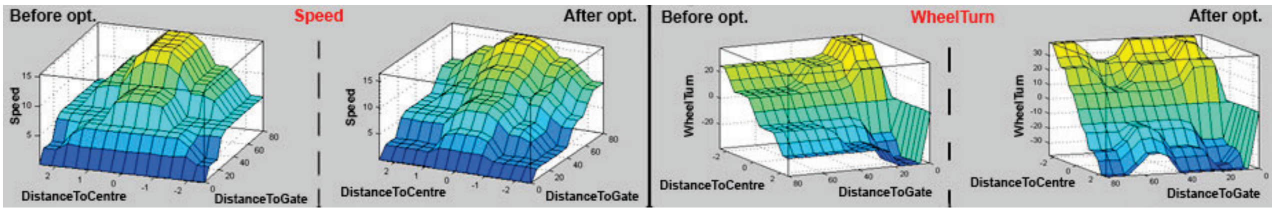


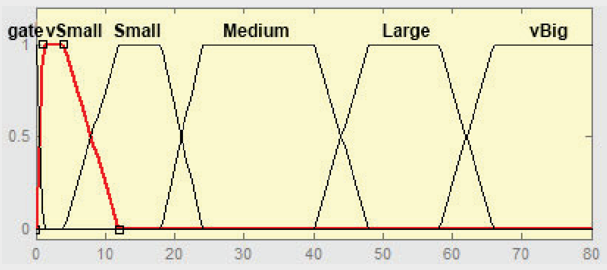
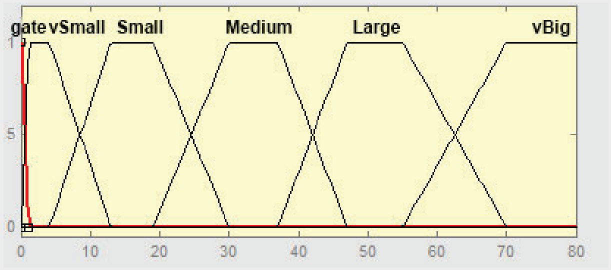
Fig. 3. Control planes before and after the first stage of optimization

As described earlier, the parameter on the axis related to the distance to the centre line is examined only on one side of the range since it is symmetrical and therefore the resulting values will be the same, however with the opposite sign. In this case, the deviation to the right was selected, therefore all the values of the wheel turn will be negative (left turn).

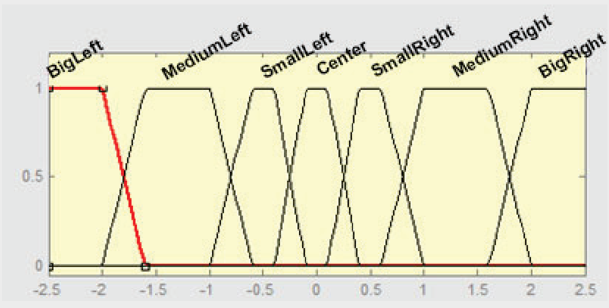
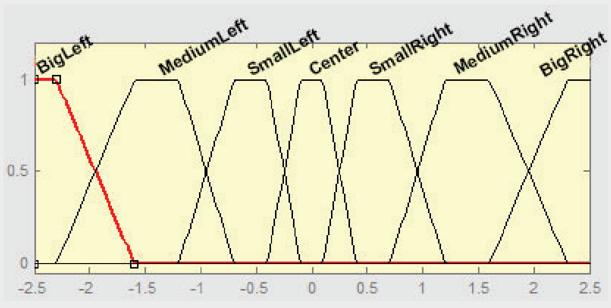
In the second stage of optimization, the authors changed the ranges of two input signals in such a way that the next function ranges of the membership functions could have a common part, to the greatest possible extent. Tab. 5 displays the ranges prior to and after optimization for both input parameters. In the "DistanceToGate", the biggest change is leaning the ranges between the functions "big" and "vBig", as well as aligning the horizontal sections between consecutive functions. It is particularly visible in the range referred to as "Medium".

The second modified parameter was "DistancetoCentre". Here the greatest change was made on the external ranges from medium to large, as can be seen in Tab. 6. At this point, the leaning is clearly increased, with the horizontal parts of the function "BigLeft" and "BigRight" dropped by more than half of the value 2 and -2 for values 2.3 and -2.3.

Tab. 5. Ranges of membership functions before and after the second stage of optimization for the parameter "DistanceToGate"

Before optimization	After optimization
	

Tab. 6. Ranges of membership functions before and after the second stage of optimization for the parameter "DistancetoCentre"

Before optimization	After optimization
	

The control planes for the speed parameter, presented below in Fig. 4, are characterized by a clear difference in the transitions between the ranges. Before the changes, one can see four "humps" of speed change, moving either along the centre line or away from it to the right or to the left. However, after the implementation of the changes, the plane became smoothened; the transitions between the ranges seemed to be smoother with slight impairment at approximately 40 metres away from the gate, and 2-2.3 m to the centre line. It is evident which aircraft plane impacts a smoother movement, which was the main goal of optimization.

The control planes in Fig. 4 for the parameter of "wheel turn" are also characterised by corrected transients. In the range of 70 to 30 meters to the gate, it is possible to observe a clear reduction in the sharp edges in the vicinity of the "peak" with negative values of wheels turning, and at the hollow with the positive angles of the turn. This allows making a statement that the leap control of the nose gear was reduced, thanks to the executed operations during the second optimization.

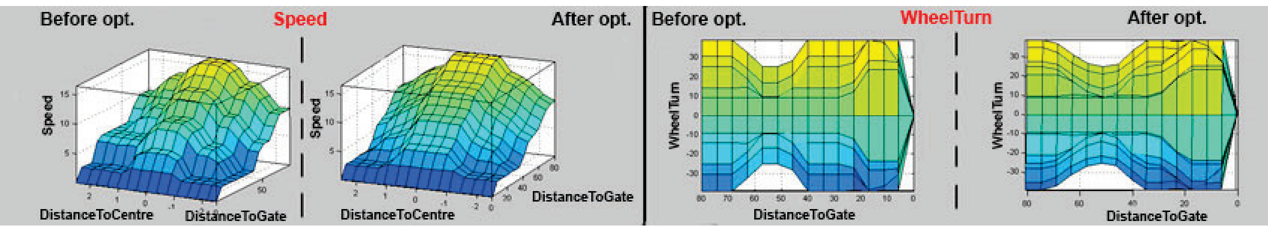


Fig. 4. Control planes before and after the second stage of optimization.

5. Conclusions

1) The automatic control of aircraft docking airplane was designed, and after undergoing modifications, it operates in accordance with the initial assumptions, i.e. by using input signals,

it is capable of generating control signals for the execution elements of the aircraft control.

2) Through a two-stage optimization, the system operation was made realistic, thus one may expect a smoother control than in the initial phase of the project, namely prior to optimization. Thanks to such solutions, it is possible to increase the comfort of the user, as well as improving attention to the execution system elements – the less leap-like and "jerky" operation of the system, the smaller consumption of particular parts. All this primarily affects the improvement of safety, reduction of the carrier costs and diminishing the time needed for taxiing. What is more, automating this process allows the use of time by pilots for other activities that so far could be performed only when the aircraft came to a halt.
3) The authors are of the opinion that the design is promising for the future and requires further development to make the operating conditions even more realistic. In the future, such a controller should be included in a larger taxi management system, from the moment the aircraft leaves a runway until reaching the parking stand.

Tab. 7. Values of output parameters depending on the inputs parameters for the designed controller

No	*Input signals*		*Output signals*			
	Distance to the centre line [m]	*Distance to the gate* [m]	*Before optimization*		*After optimization*	
			Speed [km/h]	*Wheel turn* [°]	*Speed* [km/h]	*Wheel turn* [°]
1	0	7	3.86	0	3.7	0
2	0	25	9.72	0	7.78	0
3	0	43	11.1	0	11.8	0
4	0	64	15.5	0	15	0
5	0	80	16.5	0	16.5	0
6	0.75	7	3.86	-29.2	3.7	-26.3
7	0.75	25	8.06	-15.4	7,35	-18
8	0.75	43	9.54	-15.4	11.2	-11.9
9	0.75	64	13.8	-15.4	14.4	-11.9
10	0.75	80	15.1	-15.4	16.1	-11.2
11	1.4	7	2.29	-29.2	2.27	-28.7
12	1.4	25	6	-25	4.48	-30.2
13	1.4	43	7.21	-19.1	7.97	-15.8
14	1.4	64	12.3	-21	11.8	-18.7
15	1.4	80	13.3	-25	13.3	-24.8
16	2.0	7	2.29	-38.5	2.3	-31.8
17	2.0	25	6	-38.9	4.11	-31.6
18	2.0	43	6	-32.6	6.03	-23
19	2.0	64	8.54	-34.4	9.6	-25
20	2.0	80	9.72	-38.9	11.3	-31.8

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