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STUDYING THE ABILITY OF "AUTOMOBILE – DRIVER – ROAD" SYSTEM TO BYPASS A SUDDEN OBSTACLE

The paper estimates the factors required to organize driving training on bypassing a sudden obstacle. The automobile characteristics are determined as well as control actions of the driver required to successfully bypass a sudden obstacle. Besides, a possibility of successful evaluation of the learning progress and driver's performance is determined on the basis of transient characteristics of the "automobile – driver – road" system.

Keywords: *controllability, automobile driving, training, transient characteristic.*

Introduction

The necessity to perform a lane-changing maneuver by drivers arises in the emergency situation when an obstacle appears in the lane ahead of the automobile. The possibility of performing a successful maneuver is provided by the combination of characteristics of the driver and the vehicle, driving conditions and the level of driver's training.

The existing lane-changing tests ("elk tests") [1] make it possible to investigate the most significant controllability characteristics in the "automobile – driver – road" (A – D – R) system and, primarily, the driver's response time (RT_d), the automobile response time (RT_a), their symbiosis, the type of turnability of automotive transport means (ATM). However, the driver's subjective influence is almost not taken into account, which is just the distinguishing feature of the proposed method as compared with the existing lane changing method. We believe, that with the advantages revealed in studying this vehicle maneuver taken into account, training on bypassing a sudden obstacle in the quick lane-changing manner will make it possible not only to improve driving safety skills but also to predict the driver's successful performance in other similar road situations.

Aim of the paper

1. To estimate the factors required to organize driving training on bypassing a sudden obstacle.
2. To determine characteristics of the vehicle and the driver's control actions necessary for successful bypassing a sudden obstacle.
3. To determine the possibility to estimate the driver's training progress and performance on the basis of transient characteristic values of the automatic control system (here the A – D – R system is considered), which are adopted in the automatic control theory.

Research results

Testing schemes are presented in Fig. 1. The following automobiles were used in the tests: УАЗ-3151, ГАЗ-3307, ЗИЛ-4331, Урал-4320, КрАЗ-260Б, differing by their static and dynamic characteristics of turnability (Table 1). Driving accuracy was estimated by a number of touches of the limiters using a set of instruments for registering the driver's control actions and the automobile response (DCAAR) with the application of ACS package – the Autodrome. Controllability of the vehicles was estimated by the drivers on a 10-point scale.

Driving trajectories of the automobiles were recorded with hydropneumatic trajectory tracers. Minimal distance $S_{\delta min}$, required for bypassing, was registered. It characterizes the response of both the driver and the automobile, i.e. the response of A – D system,

the deviation amplitude A_i (Fig. 2) and the length of transient characteristic S_t (Fig. 1). Stopping distance and its components were determined using a "firing device". The automobile driving parameters were recorded on the tapes of oscilloscope Н008М.

Table 1

Values of the statistical index of turnability
$U_{sc}\,L_a$ and response time - RT_{A-D} of the automobiles taking part in the experiment

Parameters	Indices of the automobiles				
	УАЗ-3151	ГАЗ-3307	ЗИЛ-4331	Урал-4320	КрАЗ-260Б
Base- L_a, м	2.38	3.3	3.975	4.2	5.3
Steering ratio - U_{sc}	20.3	20.5	20.0	21.5	23.6
$U_{sc}\,L_a$, м	48.3	67.6	79.5	90.3	125.08
RT_{A-V}, c	0.5	0.5	0.52	0.7	0.83

When processing the oscillograms and the parameters of automobile motion trajectories during the tests, the following indicators were calculated: response time RT_a of the automobile and of A – D system as a whole, RT_{D-A}, the transient process time T_t, coefficients of trajectory oscillation damping after bypass during the lane-changing maneuver, D, and of the automobile motion damping, C (Fig. 1).

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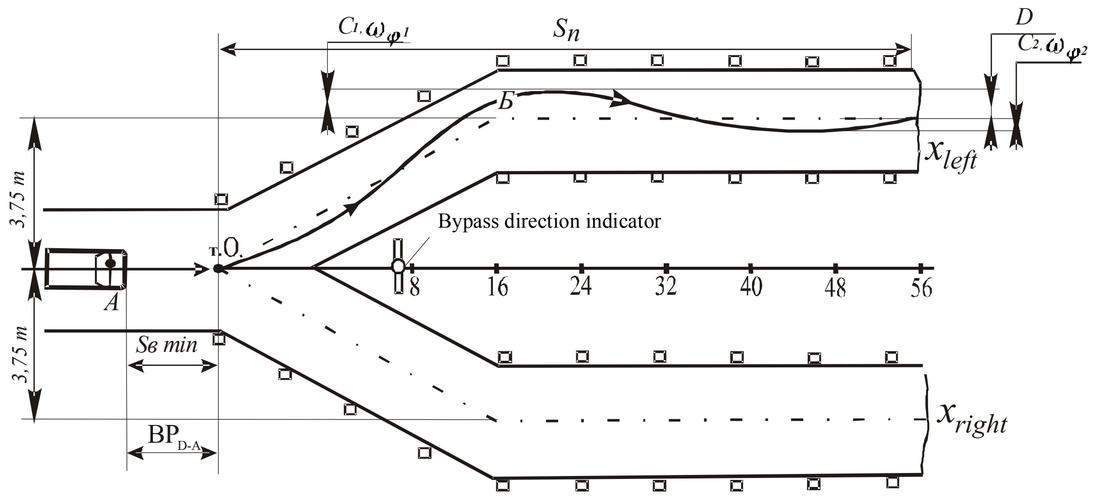

Fig. 1. Experimental route scheme "Bypassing a sudden obstacle"

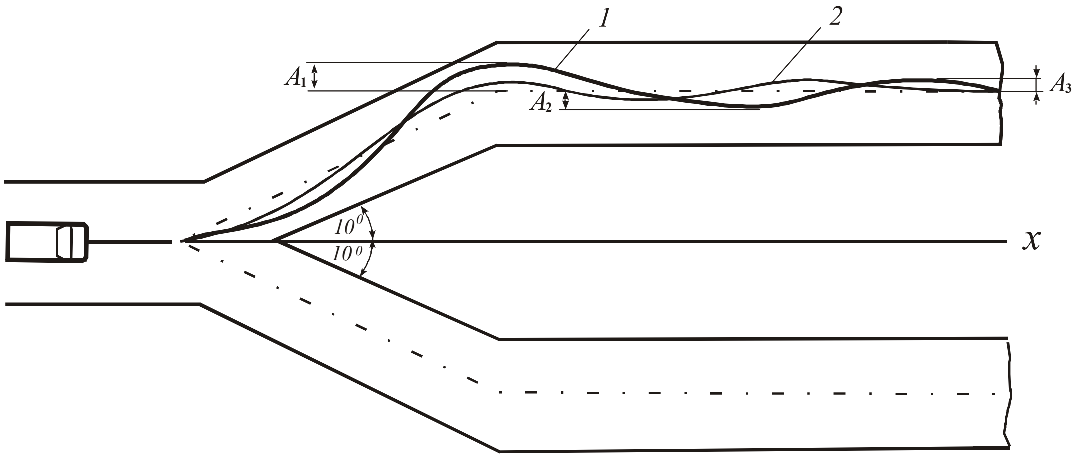

Fig. 2. Motion trajectories of the automobiles УАЗ-3151 (2) and Урал-4320 (1)

24 drivers took part in the experiment: five drivers assigned to the automobiles to be tested, four practical driving instructors with more than 5 year experience and 15 driving course students. All the 15 runs were taken into account. This made it possible to trace the process of automobile driving skill formation.

External manifistations of the compatibility of A – D system elements and the driver's level of training on bypassing a sudden obstacle are as follows: distance $S_{\delta min}$, covered by the automobile during the A – D system response time, total distance S_t, time of the transient process T_t, driving accuracy, damping coefficient D and oscillation fading coefficient C.

Fig. 2 shows the averaged motion trajectories of the automobiles for all observations; Fig. 3, 4 present the values of $S_{\delta min}$ and amplitude A of the automobile route fluctuations relative to the axial line of the traffic lane. As it was expected, atomobiles with high values of $u_{sc}L_a$ and inertia momemt $m\rho^2$ have smaller sensitivity to a turn, have higher values of $S_{\delta min}$ (from 7 – 8 m for V = 40 km / h to 17 – 20 m for 70 km / h). For the drivers of lighter and short-base automobiles this fact turned to be rather unexpected. As a result, motion trajectories of their automobiles are characterized by additional steering at the first turn дорегулированием на первой арке поворота. In this case vibration amplitude in point Б increases to 1.7…1.9 m; phase delay Ф of the automobile response increases as well.

Automobiles with a lower value of statistical turnability index $u_{sc}L_a$ are more sensitive to a turn, have higher values of $S_{\delta min}$ (for automobiles УАЗ-3151 – 4.5…4.8 m, Газ-3307 and ЗИЛ-4331 – 6…6.6 m, УРАЛ-4320 and КРАЗ-260Б – 7.2…8.8 m for V = 50 km / h). The character of their motion is distinguished by smaller oscillation amplitudes, higher oscillation frequency – up to 0.7 – 1.0 Hz. In order to keep the vehicle in the traffic lane, the drivers use the steering wheel more frequently.

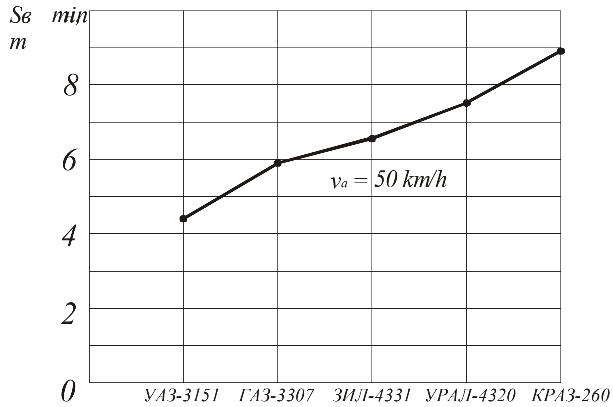

Fig. 3. Influence of the automobile type on the value of minimally safe distance $S_{\delta min}$

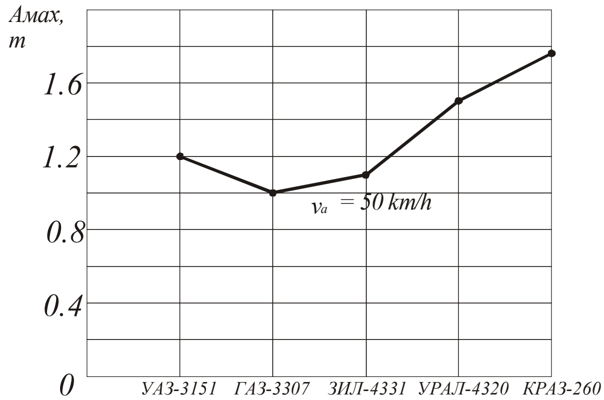

Fig. 4. Influence of the automobile type on the value of the automobile trajectory fluctuation amplitude A_{max}

Analysis of the driving accuracy indicators and subjective estimates of the automobile controllability (Fig. 5) makes it possible to assume that optimal value of $u_{sc}L_a$ is within the range of 70 – 80 m. Distribution of $u_{sc}L_a$ values for 35 domestic and Russian automobiles (Fig. 6) confirms that for most of them (УАЗ-3151, ГАЗ-3307, КАМАЗ-4310, ЗИЛ-4331, КрАЗ-260Б) this value is within the above range, for others (УРАЛ-4320) - the difference is inconsiderable. On the whole, dispersion of $u_{sc}L_a$ values is high and this should be taken into account in drivers' training and retraining as well as in the analysis of road accidents with automotive transport means.

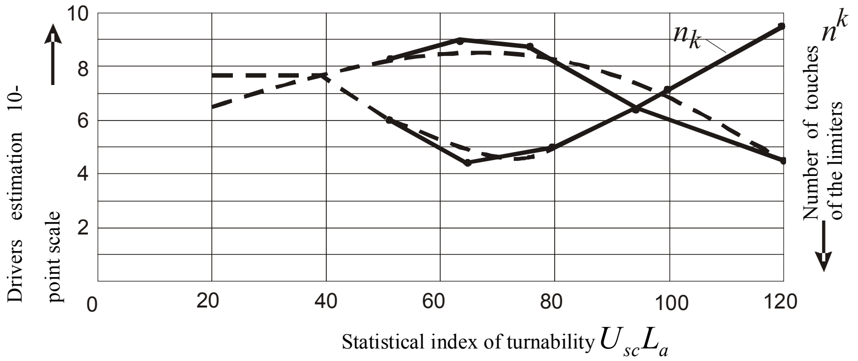

Fig. 5. Influence of U_{sc}L$_a$ parameter on the automobile controllability estimation

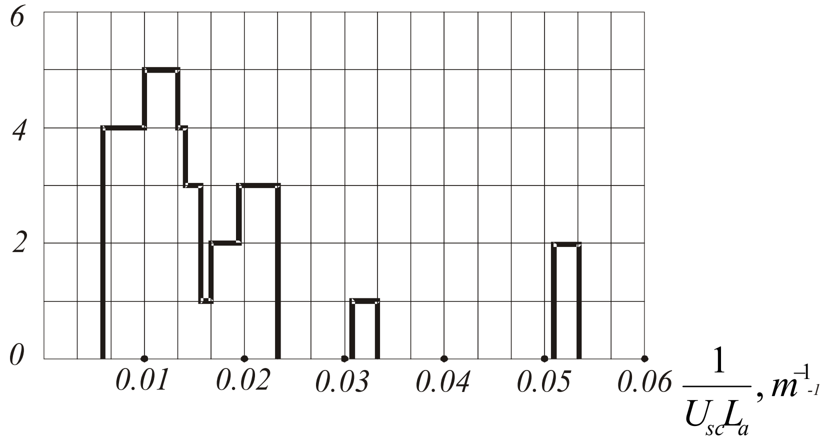

Fig. 6. Distribution of the statistical turnability index u_{sc}L$_a$ for 25 automobiles

Response time RT$_a$ of the automobiles was in the range from 0,17s for the automobile УАЗ-3151 to 0,45 s for the automobile Зил-4331 and on the whole had a significant influence not only on the total delay time of A – D system, that was 0.5…0.8 s (taking into account the drivers' readiness to the maneuver), but also on the values of time intervals between the subsequent control actions of the driver and responses of the vehicles. E.g., after the first considerable delay of the vehicle response the driver turns the steering wheel more sharply, which is accompanied by further reduction of the vehicle control modulation stability.

Thus, if we suppose that the first control action is the driver's turning the steering wheel between point A and point O (Fig. 1), the second - turning the steering wheel at the moment of placing the vehicle on the new traffic lane in the neighborhood of point Б, it could be assumed that the driver's knowledge and sensitivity to RT$_a$ will help him to get ready for peforming the second control action.

Proceeding from the driving accuracy indices and subjective estimates of the drivers (Fig. 5. 7), optimal RT$_a$ is 0,22 – 0,25 s. As RT$_a$ increases, driving accuracy becomes progressively worse. This is manifested in the unstable modulation of the automobile control system operation, in worsening of the sensomotor coordination of the driver's control actions, in the increased fluctuations of the automobile trajectory. All this happens, probably, due to the state of a certain uncertainty of A – D – R system in the interval equal to RT$_a$. This confirms the correctness of the developed informational model of A – D – R system [2].

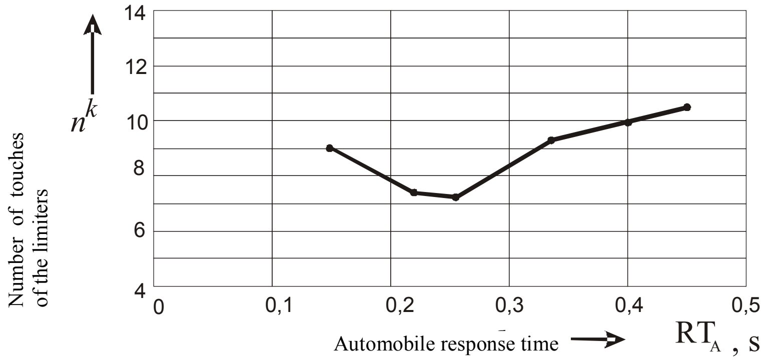

Fig. 7. Influence of the driver's response time (RT) on driving accuracy

Instability of the control is especially noticeable when the vehicle motion speed increases to 50 km / h and more. With the growth of motion speed and speed ω_{sw} of turning the steering wheel, the automobile phase response delay increases: if V = 50 km / h for the automobiles with excessive turnability (-0,17) phase delay Φ^0 is $50^0$for ω_{sw} = 180 degr.$\cdot s^{-1}$, for the automobiles with insufficient turnability (0,21) - 30^0. From Fig. 8 it is evident that phase delay of the vehicle lateral displacement relative to the turn of the steering wheel is $70\ldots120^0$ for test conditions [3].

As vehicle speed grows, $S_{\delta min}$ and S_t are increased, the transient process time of the turn T_t (Fig. 9) is reduced, but relationship between the values of S_t and T_t is nonlinear, probably, due to the vehicle trajectory fluctuations. When the driver was given the task to bypass the obstacle as fast as possible, the trajectory amplitude A_i was increased as well the automobile angular speed ω_j and the number n of readjustments ("hunting"). In such situations damping factor D had the tendency to reduce to 35%, coefficient C increased to 70%, which resulted in the increased "discomfort" of driving. It is evident, however, that drivers prefer driving safety to the comfort.

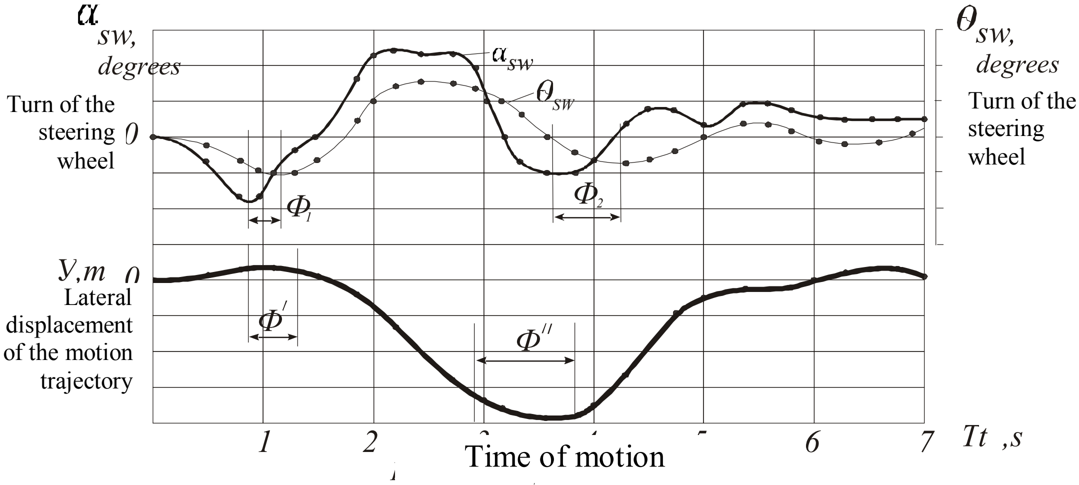

Fig. 8. Phase delays in the automobile control system

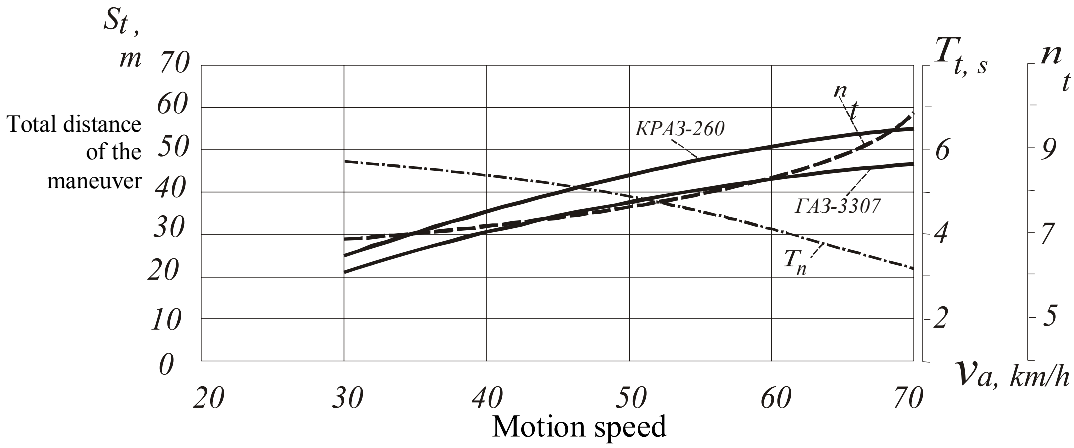

Fig. 9. Relationship between motion parameters, automobile types and driving accuracy ($n_к$)

The driver’s ability to predict events effects not only reduction of the first response delay, but also the character of subsequent actions and reactions of the automobile. To test this hypothesis, after determining the optimal values of $S_{\delta min}$ for each A – D system, organized in its own way, anticipatory (by 0.5 – 0.7 s) switching of the maneuver direction signal was provided (Fig. 1). Distance covered by the automobile was:

$$[(0{,}5 \ldots 0{,}7) \cdot V_a + S_{\delta min}]. \quad (1)$$

Indices of damping D and attenuation C of oscillations were improved. With further growth of the anticipatory period the driver’s own “noise” increased and A – D system motion parameters were not improved. .

With red traffic light the automobile was to stop and, using the “firing device”, stopping distance S_τ was determined. Fig. 10 shows changing of S_τ and $S_{\delta min}$ as a function of the vehicle motion speed.

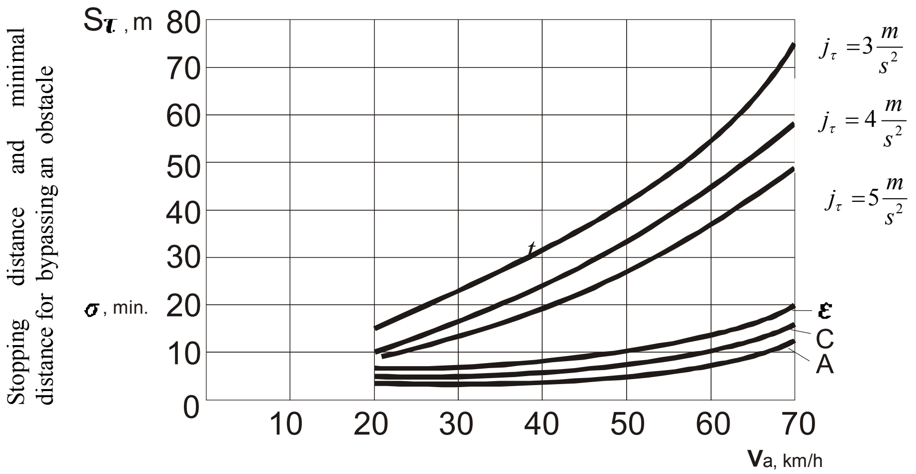

Fig. 10. Relationship between the automobile motion speed $v_{a,}$ stopping distance S_τ and minimal safe distance $S_{6\,min}$

Stopping distance was calculated by the known formula [4]:

$$S_\tau = v_0(t_0 + t_1) - \frac{j_\tau \cdot t_0^2}{6} + \frac{1}{2 j_\tau}\left(v_0 + \frac{j_\tau \cdot t}{2}\right)^2. \quad (2)$$

where t_0 – the driver's response time (t_0 = 0,75 s); t_1 – the time of the vehicle drive response (t_1 =0,5 s); j_τ – deceleration from 0,3g, 0,4g, 0,5g m· s^{-2}(sharp and rather heavy for a deiver). As it can be seen, for the automobile speed up to 50 km / h value of $S_{\delta min}$ will be a little bit higher than 1/3 of the stopping distance.

Conclusions

The maneuver on bypassing a sudden obstacle is more preferable than braking to a stop. However, it requires a timely, precisely coordinated turn of the steering wheel by the driver, knowledge and skills to detect and to react to the vehicle reponse at all phases of the maneuver. This maneuver must be further improved by achieving a combined maneuver, e. g. braking with bypassing an obstacle. This is expected to be the highest level of driving skills achieved by hard work. The proposed procedure of evaluating the driver's skills and working ability must include bypassing a sudden obstacle as a new aspect of training. Besides it could be used as preliminary training before direct training on bypassing simulated obstacles (pedestrians, vehicles). In the course of training drivers are taught to percept the vehicle characteristics, sensomotoric coordination of the control actions, acquire confidence in the capabilities of vehicles. As a result, the instructors can build a well-targeted training process.

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