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INTEGRAL INVOLVING GENERAL POLYNOMIALS, FOX'S H-FUNCTION AND MULTIVARIABLE H-FUNCTION HAVING GENERAL ARGUMENTS

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ABSTRACT

In the present paper, we obtain an integral pertaining to a product of Fox's H-function [1], general class of polynomials and general polynomials given by Srivastava [9,10] and H-function of several complex variables given by Srivastava and Panda [13] with general arguments of quadratic nature. The integral thus obtained is believed to be one of the most general integral established so far.

KeyWords. *Fox's H-function, general polynomials, multivariable H-function, general class of polynomials, generalized Lauricella function, G-function.*

1. INTRODUCTION

The H-function of several complex variables is defined by Srivastava and Panda [13] as
:

$$H[z_1,\ldots,z_r]=H^{0,\lambda:(\mu',\nu');\ldots;(\mu^{(r)},\nu^{(r)})}_{A,C:[B',D'];\ldots;[B^{(r)},D^{(r)}]}\left[\begin{matrix}[(\alpha):\theta';\ldots;\theta^{(r)}]:[(\beta'):\phi''];\ldots;[(\beta^{(r)}:\phi^{(r)}];\\(\gamma):\psi';\ldots;\psi^{(r)}]:[(\xi'):\rho'];\ldots;[(\xi^{(r)}):\rho^{(r)}];\end{matrix}\; z_1,\ldots,z_r\right] \tag{1.1}$$

The H-function of several complex variables in (1.1) converges absolutely if

$$|\arg(z_i)|<\frac{1}{2}\pi T_i, \tag{1.2}$$

where

$$T_i=\sum_{j=1+\lambda}^{A}\theta_j^{(i)}+\sum_{j=1}^{\upsilon^{(i)}}\phi_j^{(i)}-\sum_{j=1+\upsilon^{(i)}}^{\beta^{(i)}}\phi_j^{(i)}-\sum_{j=1}^{C}\Psi_j^{(i)}+\sum_{j=1}^{\mu^{(i)}}\rho_j^{(i)}-\sum_{j=1+\mu^{(i)}}^{D^{(i)}}\rho_j^{i}>0,\quad\forall\, i\in(1,\ldots,r) \tag{1.3}$$

The series representation of Fox's H-function [1]

$$H^{M,N}_{P,Q}\left[z\left|\begin{matrix}(e_P,E_P)\\(f_Q,F_Q)\end{matrix}\right.\right]=\sum_{G=0}^{\infty}\sum_{g=1}^{M}\frac{(-1)^G}{G!F_g}\phi(\eta_G)z^{\eta_G} \tag{1.4}$$

where

$$\phi(\eta_G)=\frac{\prod\limits_{\substack{j=1\\j\neq g}}^{M}\Gamma(f_j-F_j\eta_G)\prod\limits_{j=1}^{N}\Gamma(1-e_j+E_j\eta_G)}{\prod\limits_{j=M+1}^{Q}\Gamma(1-f_j+F_j\eta_G)\prod\limits_{j=N+1}^{P}\Gamma(e_j-E_j\eta_G)}$$

and

$$\eta_G=\frac{(f_g+G)}{F_g}$$

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The general polynomials have been defined and introduced by Srivastava [9] as following

$$S_{n_1,\dots,n_s}^{m_1,\dots,m_s}[t_1,\dots,t_r]=\sum_{\alpha_1=0}^{[n_1/m_1]}\dots\sum_{\alpha_s=0}^{[n_s/m_s]}\frac{(-n_1)_{m_1\alpha_1}}{\alpha_1!}\dots\frac{(-n_s)_{m_s\alpha_s}}{\alpha_s!}$$

$$.\ A[n_1,\alpha_1;\dots;n_s,\alpha_s]\ t_1^{\alpha_1}\dots t_s^{\alpha_s} \tag{1.5}$$

where $n_i=0,1,2,\dots,\forall i\,(1,\dots,s); m_1,\dots,m_s$ are arbitrary positive integers and the coefficients $A[n_1,\alpha_1;\dots;n_s,\alpha_s]$ are arbitrary constants, real or complex.

Srivastava [10] introduced the general class of polynomials

$$S_{n'}^{m'}(t)=\sum_{k=0}^{[n'/m']}\frac{(-n')_{m'k}}{k!}A\left(n',k\right)\ t^k,\ k\ =\ 0,1,2,\dots \tag{1.6}$$

where m' is an arbitrary positive integer and the coefficients $B_{n'k}(n',k\geq 0)$ are arbitrary constants, real or complex.

2. THE MAIN RESULT

In this section, we have derived the following integral

$$\int_0^\infty x^{1-a}(\alpha+\beta x+\gamma x^2)^{\alpha-\frac{3}{2}}H_{P,Q}^{M,N}\left[\left(\frac{x}{\alpha+\beta x+\gamma x^2)}\right)^{\delta}\Big|_{(f_Q,F_Q)}^{(e_P,E_P)}\right]$$

$$.\ S_{n'}^{m'}\left[t\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\eta}\right].S_{n_1,\dots,n_s}^{m_1,\dots,m_s}\left[t_1\left(\frac{x}{\alpha+\beta x+x^2)}\right)^{\eta_1}\right],\dots,$$

$$.\ t_s\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\eta_s}\Bigg]H\left[z_1\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\delta_1},\dots,z_r\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\delta_r}\right]dx$$

$$=\sqrt{\frac{\pi}{\gamma}}\sum_{G=0}^{\infty}\sum_{g=1}^{m}\sum_{k=0}^{[n'/m']}\dots\sum_{\alpha_1=0}^{[n_1/m_1]}\sum_{\alpha_s=0}^{[n_s/m_s]}\frac{(-1)^G}{G!F_g}\frac{(-n')_{m'k}}{k!}\frac{(-n_1)_{m_1\alpha_1}}{\alpha_1!}\dots\frac{(-n_s)_{m_s\alpha_s}}{\alpha_s!}\phi(\eta_G)$$

$$.\ A[n',k;n_1,\alpha_1;\dots;n_s,\alpha_s]t^k\ t_1^{\alpha_1}\dots t_s^{\alpha_s}(\beta+2\sqrt{\gamma\alpha})^{(a-\delta\eta_G-\eta k-\Sigma\eta_i\alpha_i-1)}$$

$$.\ H_{A+1,C+1;[B',D'];\dots;[B^{(r)},D^{(r)}]}^{0,\lambda+1:(\mu',\nu');\dots;(\mu^{(r)},\nu^{(r)})}\left[\begin{matrix} z_1(\beta+2\sqrt{\gamma\alpha})^{-\delta_1}\\ \vdots \\ z_r(\beta+2\sqrt{\gamma\alpha})^{-\delta_r}\end{matrix}\middle|\begin{matrix}[a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i:\delta_1;\dots;\delta_r],\\ \\ [(\gamma):\Psi';\dots;\Psi^{(r)}],\end{matrix}\right.$$

$$\left.\begin{matrix}[(\alpha):\theta^{(1)}:\dots:\theta^{(r)}]\ :\ [\beta^{(1)}:\phi^{(1)}];\dots;[\beta^{(r)}:\phi^{(r)}]\\ \\ [a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i-\frac{1}{2}:\delta_1;\dots;\delta_r]:[(\xi'):\rho'];\dots;[(\xi^{(r)}):\rho^{(r)}]\end{matrix}\right] \tag{2.1}$$

provided that Re(α) > 0, Re(β) > 0, γ > 0 and

$$\delta \min\left[\operatorname{Re}\left(\frac{f_j}{F_j}\right)\right]+\sum_{i'=1}^{r}\delta_{i'}\min\left[\operatorname{Re}\left(\frac{\xi_{j'}^{(i')}}{\rho_{j'}^{(i')}}\right)\right]>a-2,\ j=1,\dots,m \text{ and } j'=1,\dots,\mu^{(i')}.$$

Proof: In order to prove (2.1), first we express the Fox's H-function, a general polynomials and the general class of polynomials in the form of series and the H-function of several complex variables in terms of Mellin-Barnes contour integrals. Now interchanging the order of summations and integrations which is permissible under the stated conditions, we obtain

$$\sum_{G=0}^{\infty}\sum_{g=1}^{m}\sum_{\alpha_1=0}^{[n_1/m_1]}\cdots\sum_{\alpha_s=0}^{[n_s/m_s]}\sum_{k=0}^{[n'/m']}(-1)^G\frac{(-n_1)_{m_1\alpha_1}}{\alpha_1!}\cdots\frac{(-n_s)_{m_s\alpha_s}}{\alpha_s!}\frac{(-n')_{m'k}}{k!}$$

$$.\ \phi(\eta_G)A[n',k;n_1,\alpha_1;\dots;\eta_s,\alpha_s]t^k t_1^{\alpha_1}\dots t_s^{\alpha_s}\frac{1}{(2\pi i)^r}$$

$$.\ \int_{L_1}\dots\int_{L_r}\psi(\varsigma_1,\dots,\varsigma_r)\phi_1(\varsigma_1)\dots\phi_r(\varsigma_r)z_1^{\varsigma_1}\dots z_r^{\varsigma_r}$$

$$\left\{\int_0^{\infty}x^{1\left(a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i-\delta_1\varsigma_1-\dots-\delta_r\varsigma_r\right)}(\alpha+\beta x+\gamma x^2)^{\left(a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i-\delta_1\varsigma_1-\dots-\delta_r\varsigma_r\right)-\frac{3}{2}}dx\right\}d\varsigma_1\dots d\varsigma_r \qquad (2.2)$$

Evaluating the above x-integral with the help of a known theorem (Saxena [8]) and reinterpreting the result thus obtained in terms of H-function or r-variables, we reach at the desired result.

3. SPECIAL CASES

(I) Taking $\theta',\dots,\theta^{(r)}=\phi',\dots,\phi^{(r)}=\psi',\dots,\psi^{(r)}=\rho',\dots,\rho^{(r)}=\delta_1,\dots,\delta_r=a',\dots,a^{(r)}$ in (2.1), we get the following integral transformation:

$$\int_0^{\infty}x^{1-a}(\alpha-\beta x+\gamma x^2)^{a-\frac{3}{2}}H_{P,Q}^{M,N}\left[\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\delta}\middle|\begin{matrix}(e_P,E_P)\\(f_Q,F_Q)\end{matrix}\right]$$

$$.S_{n'}^{m'}\left[t\left(\frac{x}{\alpha+\beta x+yx^2}\right)^{\eta}\right].S_{n_1,\dots,n_s}^{m_1,\dots,m_s}\left[t_1\left(\frac{x}{\alpha+\beta x+\gamma x^2)}\right)^{\eta_1},\dots,t_s\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\eta_s}\right]$$

$$.G_{A:C:[B',D'];\dots;[B^{(r)},D^{(r)}]}^{0,\lambda:(\mu',\nu');\dots;(\mu^{(r)},\nu^{(r)})}\left[z_1^{1/a'}\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right),\dots,z_r^{1/a^r}\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)\middle|\begin{matrix}(\alpha):(\beta');\dots;(\beta^{(r)})\\(y):(\xi');\dots;(\xi^{(r)})\end{matrix}\right]dx$$

$$=\sqrt{\frac{\pi}{\gamma}}\sum_{G=0}^{\infty}\sum_{g=1}^{m}\sum_{k=0}^{[n'/m']}\cdots\sum_{\alpha_1=0}^{[n_1/m_1]}\sum_{\alpha_s=0}^{[n_s/m_s]}\frac{(-1)^G}{G!F_g}\frac{(-n')_{m'k}}{k!}\dots\frac{(-n_1)_{m_1\alpha_1}}{\alpha_1!}\frac{(-n_s)_{m_s\alpha_s}}{\alpha_s!}\phi(\eta_G)$$

$$.\ A[n',k;n_1,\alpha_1;\dots;n_s,\alpha_s]t^k t_1^{\alpha_1}\dots t_s^{\alpha_s}(\beta+2\sqrt{\gamma\alpha})^{(a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i-1)}$$

$$.\ G_{A+1,C+1:[B',D'];\dots;[B^{(r)},D^{(r)}]}^{0,\lambda+1:(\mu',\nu');\dots;(\mu^{(r)},\nu^{(r)})}\left[z_1^{\frac{1}{a'}}(\beta+2\sqrt{\gamma\alpha})^{-1},\dots,z_r^{\frac{1}{a^r}}(\beta+2\sqrt{\gamma\alpha})^{-1}\right|$$

$$\left.\begin{matrix}\left[a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i\right];(\alpha):(\beta');\dots;(\beta^{(r)})\\(\gamma),\left[a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i-\frac{1}{2}\right]:(\xi');\dots;(\xi^{(r)}\end{matrix}\right] \qquad (3.1)$$

provided that $\operatorname{Re}(\alpha) > 0,\ \operatorname{Re}(\beta) > 0,\ \gamma > 0; 0\, a^{(i)} > 0\quad (i=1,\ldots,r), 2(\mu^{(i)}+\nu^{(i)}) >$ $(A+C+B^{(i)}+D^{(i)}), |\arg(z_i)| < \left[\mu^{(i)}+\nu^{(i)}-\frac{A}{2}-\frac{C}{2}-\frac{B^{(i)}}{2}-\frac{D^{(i)}}{2}\right]\pi$ and

$$\delta\left\{\min_{1\le j\le m}\left[\operatorname{Re}\left(\frac{f_j}{F_j}\right)\right]\right\}+\sum_{i=1}^{r}\{\min_{1\le j\le \mu^{(i)}}[\operatorname{Re}(\xi_j^{(i)})]\} > a-2.$$

(II) When $\lambda = A = C = 0$ in (2.1), we get the following transformation:

$$\int_0^\infty x^{1-a}(\alpha+\beta x+\gamma x^2)^{a-\frac{3}{2}} H_{P,Q}^{M,N}\left[\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\delta}\middle|\begin{matrix}(e_P,E_P)\\(f_Q,F_Q)\end{matrix}\right]$$
$$.S_{n'}^{m'}\left[t\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\eta}\right].S_{n_1,\ldots,n_s}^{m_1,\ldots,m_s}\left[t_1\left(\frac{x}{\alpha+\beta x+\gamma x^2)}\right)^{\eta_1},\ldots,t_s\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\eta_s}\right]$$
$$.\prod_{i=1}^{r} H_{B^{(i)},D^{(i)}}^{\mu^{(i)},\nu^{(i)}}\left[z_i\left(\frac{x}{\alpha+\beta x+yx^2}\right)^{\delta_1}\middle|\begin{matrix}[(\beta^{(i)}):(\phi^{(i)})]\\ [(\xi^{(i)}):(\rho^{(i)})]\end{matrix}\right]dx$$

$$=\sqrt{\frac{\pi}{\gamma}}\sum_{G=0}^{\infty}\sum_{g=1}^{m}\sum_{k=0}^{[n'/m']}\cdots\sum_{\alpha_1=0}^{[n_1/m_1]}\sum_{\alpha_s=0}^{[n_s/m_s]}\frac{(-1)^G}{G!F_g}\frac{(-n')_{m'k}}{k\,!}\cdots\frac{(-n_1)_{m_1\alpha_1}}{\alpha_1!}\frac{(-n_s)_{m_s\alpha_s}}{\alpha_s!}\phi(\eta_G)$$
$$.\ A[n',k;n_1,\alpha_1;\ldots;n_s,\alpha_s]\,t^k\,t_1^{\alpha_1}\ldots t_s^{\alpha_s}(\beta+2\sqrt{\gamma\alpha})^{a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i-1}$$
$$.\,H_{1,1:[B',D'];\ldots;[B^{(r)},D^{(r)}]}^{0,1:(\mu',\nu');\ldots;(\mu^{(r)},\nu^{(r)})}\left[\begin{matrix}z_1(\beta+2\sqrt{\gamma\alpha})^{-\delta_1}\\ \vdots\\ z_r(\beta+2\sqrt{\gamma\alpha})^{-\delta_r}\end{matrix}\middle|\begin{matrix}\left[a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i:\delta_1;\ldots;\delta_r\right]:(\beta'):\phi']\,;\ldots;[(\beta^{(r)}:\phi^{(r)}]\\ \left[a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i-\frac{1}{2}:\delta_1;\ldots;\delta_r\right]:(\xi'):\rho']\,;\ldots;(\xi^{(r)}:\rho^{(r)}]\end{matrix}\right] \tag{3.2}$$

valid under the same conditions as obtainable from (2.1).

(III) Taking $\lambda = A, \mu^{(i)}=1, \nu^{(i)}=B^{(i)}$ and $D^{(i)}=D^{(i)}+1\,\forall\, i\in(1,\ldots,r)$ the result in (2.1) reduces to the following integral transformation:

$$\int_0^\infty x^{1-a}(\alpha-\beta x+\gamma x^2)^{a-\frac{3}{2}} H_{P,Q}^{M,N}\left[\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\delta}\middle|\begin{matrix}(e_P,E_P)\\(f_Q,F_Q)\end{matrix}\right]$$
$$.S_{n'}^{m'}\left[t\left(\frac{x}{\alpha+\beta x+yx^2}\right)^{\eta}\right].S_{n_1,\ldots,n_s}^{m_1,\ldots,m_s}\left[t_1\left(\frac{x}{\alpha+\beta x+yx^2)}\right)^{\eta_1},\ldots,t_s\left(\frac{x}{\alpha+\beta x+yx^2}\right)^{\eta_s}\right]$$
$$.F_{C:D';\ldots;D^{(r)}}^{A:B';\ldots;B^{(r)}}\left[-z_1\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\delta_1},\ldots,-z_r\left(\frac{x}{\alpha+\beta x+\gamma x^2}\right)^{\delta_r}\right|$$

$$\left.\begin{matrix}[1-(\alpha):\theta';\ldots;\theta^{(r)}]:[1-(\beta'):\phi;];\ldots;[1-\beta^{(r)}:\phi^{(r)}]\\ [1-(\gamma):\psi';\ldots;\psi^{(r)}]:[1-(\xi'):\rho'];\ldots;[1-(\xi)^{(r)}:\rho^{(r)}]\end{matrix}\right]dx$$

$$= \sqrt{\frac{\pi}{\gamma}} \sum_{G=0}^{\infty} \sum_{g=1}^{m} \sum_{k=0}^{[n'/m']} \cdots \sum_{\alpha_1=0}^{[n_1/m_1]} \sum_{\alpha_s=0}^{[n_s/m_s]} \frac{(-1)^G}{G!\,F_g} \frac{(-n')_{m'k}}{k\,!} \cdots \frac{(-n_1)_{m_1\alpha_1}}{\alpha_1\,!} \frac{(-n_s)_{m_s\alpha_s}}{\alpha_s\,!}\, \phi(\eta_G)$$

$$.\ A[n',k;n_1,\alpha_1;\ldots;n_s,\alpha_s]\, t^k\, t_1^{\alpha_1}\ldots t_s^{\alpha_s}\,(\beta+2\sqrt{\gamma\alpha})^{a-\delta\eta_G-\eta k-\sum_{i=1}^{s}\eta_i\alpha_i-1}$$

$$.\ \frac{\Gamma\left(1-a+\delta\eta_G+\eta k+\sum_{i=1}^{s}\eta_i\alpha_i\right)}{\Gamma\left(\frac{3}{2}-a+\delta\eta_G+\eta k+\sum_{i=1}^{s}\eta_i\alpha_i\right)} F^{A+1:B';\ldots;B^{(r)}}_{C+1:D';\ldots;D^{(r)}}\left[\begin{matrix} z_1(\beta+2\sqrt{\gamma\alpha})^{-\delta_1}\\ \vdots \\ z_r(\beta+2\sqrt{\gamma\alpha})^{-\delta_r}\end{matrix}\right|$$

$$\left.\begin{matrix}\left[1-a+\delta\eta_G+\eta k+\sum_{i=1}^{s}\eta_i\alpha_i:\delta_1;\ldots;\delta_r\right],[1-(\alpha):\theta';\ldots;\theta^{(r)}]:[1-(\beta'):\varphi'];\ldots;[(1-\beta^{(r)}:\varphi^{(r)}]\\ [1-(\gamma):\psi';\ldots;\psi^{(r)}],\left[\frac{3}{2}-a+\delta\eta_G+\eta k+\sum_{i=1}^{s}\eta_i\alpha_i:\delta_1;\ldots;\delta_r\right]:[1-(\xi'):\rho'];\ldots;(1-\xi^{(r)}:\rho^{(r)}]\end{matrix}\right] \tag{3.3}$$

provided that Re $(\alpha) > 0$, Re$(\beta) > 0$, $\gamma > 0$, the series on the right side exists.

(IV) Replacing $n_1,\ldots,n_s$ by n and $n' \to 0$, the result in (2.1) reduces to the known result given in [2], after a little simplification.

(V) Taking $n_i \to 0$ ($i = 1,\ldots,s$), $n' \to 0$, $\alpha = 0$, $\gamma = 1$, the result in (2.1) reduces to the known result after a small simplification obtained by Goyal and Mathur [5].

(VI) If $r = 1$ and m_i, $n_i \to 0$ ($i = 2,\ldots,s$), $n' \to 0$, the result in (2.1) reduces to the known result with a small modification derived by Gupta and Jain [6].

(VII) If $n' \to 0$, the result in (2.1) reduces to the known result obtained by Chaurasia and Shekhawat [3].

4. CONCLUSION

The main result of this paper is sufficiently general in nature and is capable of yielding numerous (known or new) findings involving classical orthogonal polynomials hitherto scattered in the literature.

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